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Ship Hydromechanics Department

**SEAKEEPING CRITERIA FOR 47-FT, 82-FT,
AND THE 110-FT U.S. COAST GUARD
CUTTERS**

By

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ABSTRACT

The 1993 USCG Boat Series study was initiated to define a set of seakeeping criteria to distinguish the seakeeping merits of a range of boats each with the same mission profile and operational areas. The merits of the seakeeping performance was measured by the speed weighted percent time of operation, WPTO. It was determined that neither pitch nor heave motion components can be affected by boat design for a given size because the boats spend a very large part of their operating time in the "wave contouring" mode. The best distinguishing criteria among the different boats was roll motion and crew performance limiting criteria of Motion Induced Interruptions and Motion Sickness Incidence. These crew performance limiting criteria were strongly affected by roll motions.

ADMINISTRATIVE INFORMATION

The application of current US Navy Seakeeping Programs to the development of seakeeping criteria for assessment of the performance capability of three US Coast Guard boats was funded by the US Coast Guard and charged to work unit number 1-1561-059-01. The development of the Motion Induced Interruption criteria and incorporation of it into the Seakeeping Evaluation Program was funded by the US Navy and performed in 1992 under work unit number 1-1506-222-30.

OBJECTIVE

The objective of the study was to define a set of seakeeping criteria to distinguish the seakeeping merits of a range of boats each with the same mission profile and operational areas. The merits of the seakeeping performance is measured by the percent time of operation, PTO. This in turn represents the time of operation that the boats could operate without exceeding the criteria in the areas of operation. This represents a number which does not include the issue as to whether or not the boat is READY to be used. The PTO is weighted by the amount of time that the ship speed is to be required relative to other ship speeds.

APPROACH

The investigation into appropriate seakeeping criteria applicable for the selection of the most capable boat from seakeeping considerations rests on examination of three existing USCG boats. Specific particulars of these boats are summarized in Figures 1 and 2 as well as Tables 1 and 2. These boats in turn span the range of sizes which could potentially perform the required mission. Existing US Navy computer programs (as defined in Table 3) and published criteria data were used to construct the PTO, see References 1 through 15. However the seakeeping criteria were revised to reflect the differences between ships for which the criteria were initially developed and these boats as well as advances in techniques of determining criteria.

Percent Time of Operation

The ability of a ship to change speed and heading alters at the command of the operator, the relative wind, wave, current, and the resulting ship motions that impact the ability to carry out the ship or boat mission. Two limiting cases are considered to determine the percent time of operation, PTO, when the ship mission can be carried out. These cases are designated as restricted and unrestricted operations. The first case is referred to as restricted operations where the ship is considered to be operationally constrained to a particular speed and heading. Such constraints could be due to underway replenishment operations, UNREP, array deployments, the need to transit to a specific point etc. The percent time of operation for restricted operations represents the normal output results for the Seakeeping Evaluation Program, SEP. In the second case, the ship/boat is free to assume any speed and heading to accomplish its mission.

To calculate the percent operability for the restricted case, the operability at each speed-heading combination due to the given wave height-wave period-wind speed joint probability distribution is calculated. The operabilities are then combined, weighted by the probability of occurrence of each speed-heading combination. Thus this final summation for the restricted PTO is over wave height-wave period-wind speed and ship speed-heading.

The second case for unrestricted operability is more complex. For each wave height-wave period-wind speed combination, the ship assumes the "best" speed-heading. That is, since all criteria are pass-fail, if there is any speed-heading combination at which the criteria are all passed, that wave height-wave period-wind speed probability is given a weight of one times its probability of occurrence in the final summation. This summation for the unrestricted PTO is taken only over wave height-wave period-wind speed (not ship speed-heading). Clearly this latter unrestricted operability is the operability required if speed and heading variations are to be permitted to the ship in carrying out its mission such as for example the launching of a boat or the recovery of either a boat or subject/object from the water.

WPTO Speed-Heading Weighting Factors

A speed-heading weighting was applied to the PTO to yield a weighted percent time of operation, WPTO. The same weighting factors were applied for speed and for each boat. All data in Figures and Tables are WPTO unless otherwise stated. Table 4 presents the speed-heading weights used in this study although only an example is shown for the 110-Ft cutter operating at the economical speed. For the low speed case the weighting was applied to each boat at 0 and 5 knots equally, whereas for the economical and high speeds the heading weights were applied to the appropriate speed for the individual boat. The heading conventions used for the Ship Motions Program, SMP and the Seakeeping Evaluation Program (SEP), is provided in Table 5.

In this current study the boat responses were calculated for 24 individual headings relative to the waves i.e. headings were varied from head seas in 15 degree increments. Head and following seas headings were weighted twice as much as for any of the other headings to account for a common operator bias for head and following seas. These same heading weighting factors were used for all speed and boat calculations except the ones summarizing the small boat launching and retrieval operability. These in turn were applied to restrict the boats operations to only three headings and a single speed i.e. following seas as well as 15 and 30 degrees off the port quarter at 5 knots.

WPTO results were combined for the individual boats in accordance with the operational frequency of use specified in the Statement of Work, Appendix G. These results are shown in Figures 15 through 27 along with the WPTO results for the individual speeds and boats.

Steps in Analysis Approach

A brief summary of the steps involved in this investigation is as follows:

1. Construct a wave data base representative of the intended operational areas for the boats.
2. Next assemble the boat particulars information required to construct a complete Ship Motion Program input deck for each of the three boats for a near full load configuration representative of their deployed status.
3. Next for the stabilized variant of the largest boat, select a "design" sea state for the fin system. Select typical characteristics of the system including limit angles to which the fins are to operate. Then determine the required fin gain values.
4. Run SMP for each of the boats at each required operational speed and develop complete outputs in the fin design sea state to serve as a quality control check for each of the motions and criteria selected.
5. Verify the individual sets of results for each motion channel and criteria.
6. Select 10 degrees (for small boats) as the roll value for which the transfer functions are to be calculated.
7. Run SMP for all of the required boat/speed conditions to construct the transfer function files required as the input for SEP.
8. Run SEP for selected boat/speed cases to verify that the results are correct and that the input to SEP is completely correct. Make corrections to the SEP input as required.
9. Examine in detail each of the proposed criteria and either accept, update or reject and delete the criteria. Employ source references for the criteria and related published sea trials or current experimental results to establish a final base criteria set.
10. Conduct sensitivity analysis on the value for each of the limiting criteria.
11. Run SEP for all required boat/speed/sea condition (including area & season) to develop a set of Weighted Percent Time of Operation, WPTO's.
12. Tabulate the WPTO's and construct graphs of the results. Examine the results in detail and establish the reasons for apparent anomalies.
13. Commence Quality Assurance Phase of study to insure that each step of the procedure is correct and used the best available information.

14. Correct the SMP frequency distribution to assure that the short roll periods of the boats are accurately reflected in the base set of wave frequencies used in SMP-91.
15. Modify SMP-91 to more accurately solve for the boat roll and then rename the program for identification purposes as SMP-93.
16. Repeat a set of SMP calculations for the entire speed set of one boat and compare the revised with the previous results. Conclude that at the lower speeds there is a substantial difference in roll and vertical accelerations.
17. Conclude that ALL of the SMP and SEP runs need to be repeated and results then tabulated and graphed.
18. Execute the first complete repeat of the calculations with SMP and the subsequent analysis of results for anomalies in results.
19. Conclude that the input wave periods for SEP derived from the measured wave data base is too coarse to accurately reflect the relative frequency of the waves that cover the range of dynamic boat responses. Alter and expand the two NOAA Buoy wave period range from a four to seven period set.
20. Repeat all SEP and related calculations. Tabulate the WPTO results and graph the same. Examine to determine the influence of this modification/correction in wave frequency of occurrence distribution.
21. Conduct Seakeeping Criteria Sensitivity on WPTO study to verify that the final base criteria selected represent the appropriate set.

Data Analysis

Ship Motion Definitions

Ship motions in this study were computed using the standard, validated and documented US Navy surface Ship Motions Program designated as SMP and defined by the users manual of References 12 and 13. The basic 6 degrees of ship motions consist of three linear and three angular motions. From these basic motions referenced to the origin all other ship required motion responses were calculated.

The three linear displacements in the x, y, and z directions are defined respectively as surge, sway and heave. In SMP, positive surge is forward, positive sway is to port and positive heave is up. The three angular motions about the x, y, and z axes are defined as roll, pitch and yaw. Positive roll is starboard side down, positive pitch is bow down and positive yaw is bow to port. The origin of SMP's right handed coordinate system is at the longitudinal center of gravity in the waterplane. This origin moves forward at the mean speed of the ship.

When the ship is regarded as a rigid, nonflexing body, the linear displacements for any location on the ship are obtained from the 6 degree of freedom motions by:

$$\begin{aligned}
 x &= \text{surge} - y_{\text{bar}} * \text{yaw} + z_{\text{bar}} * \text{pitch} \\
 y &= \text{sway} - z_{\text{bar}} * \text{roll} + x_{\text{bar}} * \text{yaw} \\
 z &= \text{heave} - x_{\text{bar}} * \text{pitch} + y_{\text{bar}} * \text{roll}
 \end{aligned}$$

where \bar{x} , \bar{y} and \bar{z} are the moment arms in feet from the origin of the coordinate system at the LCG in the waterplane.

The angular ship motions of course are the same at any point on the ship. The linear ship motions on the other hand as can be noted from the above expression vary as a function of the position on the ship. Linear velocities, or accelerations at any point of the ship can of course be obtained by single or double differentiation respectively. Thus the ship induced acceleration forces acting on the crew and shipboard equipment at arbitrary points are mixtures of angular motions times moment arms and the pure linear motion.

Natural Motion Period of Ships and Boats

The definition of the natural roll, pitch and heave periods correspond to the peak of the zero speed, transfer functions in beam seas for roll and heave displacement and in head seas for pitch.

The natural ship motion period data result for a variety of typical naval ships including the small USCG boats under consideration in this study are shown in Table 6. The speed selection summary for 1993 CG boat series is given in Table 7.

Ship Motions and Boat Motions

A ship/boats dynamic motion response characteristics are to a large extent determined by the natural periods of these motions. Clearly for larger ships the periods tend to get longer. Table 6 of the previous section on Natural Motion Periods of Boats and Ships presents specific data on these motions periods. As an example consider the natural periods for typical US Navy ships for which the ship motion criteria used in current design practice have been slowly developed. Note that the heave periods of the carriers, auxiliaries, destroyers, and frigates are always much shorter than the pitch and the roll periods. In fact, when comparing the heave periods to the roll periods, the differences are greater than a factor of 2 except for the very unusual, stiff in roll former CV41. When the USCG boats natural periods are examined it becomes apparent that the differences between the individual natural response periods are only the order of one second or less with the exception of the 47-Ft boats apparent heave natural period.

Furthermore in contrast to larger naval or USCG ships, boats tend to be very stiff due to roll stability requirements that result because of boats small sizes relative to the encountered waves. Thus boats tend to have proportionally shorter roll periods than ships and this in turn will affect (increase) the level of the roll associated accelerations. It is important to recognize that the boats are different from the ships because they are essentially shorter and stiffer in roll than ships. Thus boats encounter all of their motion natural periods and maximum responses at the shorter periods and thus also the shorter, more frequently occurring waves than waves which would tend to produce large ship motions.

Motion Response Characteristics

The overwhelming majority of ships and boats operated by the US Navy and US Coast Guard, CG, are of the monohull hull type. For such a monohull type, the maximum pitch will occur in a head/bow seas ± 45 degrees.

For short seas relative to the natural pitch periods of the ship, the ship's maximum pitch will tend to occur at the periods of encounter that are close to, though shorter than, the natural period of the ship. In other words, the heavily damped ship pitch motion response dynamics yield no response at very short waves and then the response increases to a maximum before the ship's natural period is encountered. It is this portion of the response that is of interest for the short period wave encounters. This means that for short seas, ship operations slightly away from head seas will produce larger pitch motions because they will contain the energy nearer to the natural pitch period of the ship.

Generally, the motion responses for boats limit the ability of the crew to function well before the boat systems are endangered. The vertical responses translate into the speed limiting or voluntary speed reductions by limiting slamming, wetness and associated visibility restrictions and vertical accelerations. These vertical accelerations in turn also produce crew performance limiting criteria. These are represented in this current study by both motion sickness incidence, MSI, and very serious motion induced interruptions, MII's, characterized by lifting off the deck. The lateral responses produce similarly generally excessive lateral forces which in turn result in the crew tipping as the overall forces grow to the point that unsecured standing becomes impossible. The 1992 Motion Induced Interruption, MII, Experiments at the Naval Biodynamics Laboratory confirmed the general simple theory of MII's that was incorporated into the Seakeeping Evaluation of these three CG boats with known operational histories and characteristics.

Ship/Boat Motion Predictions

Ship Motion Prediction details are presented in considerable detail in Appendix C. In this appendix the basic ship motion characteristics are reviewed by starting from the transfer functions, contrasting boat motions and ship motions and then looking at the components of the motions to define which components can be affected by the designer and why they should and can be altered. Finally a brief comparison of the roll and vertical accelerations at the Pilot House for the 1993 CG boat series is shown for typical shortcrested 2 foot significant wave height with periods ranging from 3.1 to 6.3 seconds.

The Appendix C data on transfer functions of the boats' responses illustrate that boats unlike ships tend to have their major dynamic responses of roll over a wider range of wave lengths due in general to the stiffer roll characteristics. Furthermore, the rapid roll motions add very substantially to the vertical motion and thus also vertical accelerations as movement of crew or equipment away from the boats centerline occurs. Thus the negative impact of roll motions which is the addition of the roll to the vertical mode of motions at points away from the centerline is very much accentuated for boats while the other common negative aspect of roll which is the production of destabilizing lateral forces is also retained. In short roll is a serious degrading crew performance parameter that requires considerable design effort for boats.

1993 USCG Boat Series Wave Data Base

Measured sea conditions for the CG operational areas of interests have been developed as input files into SEP for this 1993 CG Boat Seakeeping Criteria study. The individual locations of this CG wave data base are shown in Figure 3. Figure 4 presents the percentage occurrence of wave period and the maximum measured wave heights in the

period ranges. Some typical results contained in this data base are shown for the worst location, grid point 405, off the northeastern US Atlantic coast. Similarly a second more typical location in the Atlantic is also provided for grid point 401. In order to illustrate the differences between oceans, grid point 613 in the Pacific was also extracted and shown. The remainder of the data base as well as details of its verification are included in Appendix B.

A typical extract from wave data base for the 1993 USCGC 47-Ft, 82-Ft and 110-Ft Boat Series CG Operational Areas is shown below for three locations. Two of these are on the North Atlantic coast while the third one is on the US Pacific coast. It is noted that this source data comes from the measurement made with NOAA wave buoys. The data base contains the information sorted for annual as well as seasonal statistics.

Annual - GRID POINT 405 Latitude 42.7N Longitude 68.3W
Representative of WORST Point in Data Base

Wave Period (sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0...	Tot %
>15.5	0	.1	*	*	*	*	*	0	0	0	.1
11.6 - 15.5	0	.5	.8	.7	.5	.2	.1	*	*	*	2.7
7.6 - 11.5	.1	17.8	11.5	6.5	5.1	2.1	.6	.2	*	*	44.0
3.5 - 7.5	.2	23.3	21.6	6.6	.4	.6	.2	*	*	*	52.0
<3.5	.1	1.1	*	*	0	0	0	0	0	0	1.2

Annual - GRID POINT 403 Latitude 30.3N Longitude 80.4W
Representative of AVERAGE Point in Data Base

%	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	... Tot
>15.5	0	0	*	0	0	0	0	0	0	0	*
11.6 - 15.5	0	.8	1.8	.8	.1	0	0	0	0	0	3.4
7.6 - 11.5	.1	27.7	12.4	3.3	1.0	0	0	0	0	0	44.6
3.5 - 7.5	*	26.3	17.7	2.8	.1	0	0	0	0	0	47.0
<3.5	0	5.0	0	0	0	0	0	0	0	0	5.0

Annual - GRID POINT 613 Latitude 38.2N Longitude 123.3W
Representative of Typical Pacific Point in Data Base

%	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	... Tot
>15.5	0	1.1	2.3	1.8	1.2	.6	.3	.1	*	*	7.5
11.6 - 15.5	0	3.9	10.5	10.6	4.7	1.2	.2	*	*	*	31.2
7.6 - 11.5	*	8.5	21.7	12.1	3.5	.6	.1	*	0	0	44.6
6.0 - 7.5	*	1.3	6.1	3.7	.2	0	0	0	0	0	11.3
<6.0	0	1.1	2.2	.1	0	0	0	0	0	0	3.6

* = less than .1%

A brief comparison between the differences in the wave characteristics visible in these typical CG operating locations as well as the associated impact will be made based on these extracts from the 1993 USCG Boat Series wave data base.

When the three locations are contrasted it may be seen that for the worst point in the data base, somewhat more than 10% of the waves occur with heights greater than 4 meters whereas in the more typical

location less than 1.3% of the waves occur with such heights. When the typical Pacific area is examined it is quickly noted that here that more than 12.5% of the waves occur with heights of 4 meters or greater.

However, when the wave periods rather than the wave heights are examined it becomes quickly apparent that in the Pacific, the waves are simply much longer, where fully 7.5% of the waves have periods of >15.5 seconds whereas for the so called worst Atlantic location this percentage is only about .1%. Similarly, in the Atlantic locations fully 53% of the measured waves have periods equal to or less than 7.5 seconds whereas only about 15% of the waves in the typical Pacific location are less than 7.5 seconds or less. Since the natural boat motion periods are on the order of 4 seconds it is clear that the boats will experience the shorter waves which substantially amplify the boat responses more than 3 times as frequently on the North Atlantic coast than on the Pacific coast.

In SEP's limiting significant wave height computations, the wave data considered are those which encompass 95 percent of the data which occur in each significant wave height band. Since the natural boat motion periods are around 4 seconds, some of the shorter wave period data may be left out in the limiting significant wave height calculations. However, the Percent Time of Operation values utilize all of the wave data at each specified geographical location and season. The impact of this 95 percent wave data calculation procedure is on the sensitivity of PTO to variations in the values of criteria and the identity or frequency of occurrence of the limiting criteria.

A comparison of the Spectral Ocean Wave Model (SOWM) data with the buoy data is provided in Appendix B. In addition this appendix also contains a comparison of the "fit" of spectral families and measured wave spectra. This spectral family comparisons includes the Bretschneider spectral family that is assumed within SEP in this study.

Calculation Conditions and Boat Particulars

The Statement of Work requested a total of 80 Mission Performance Indices and these have been defined to the Weighted Percent Time of Operation, WPTO. As a brief review, these 80 WPTO's consist of the product of

4 vessels * 2 operational conditions (speeds) * 10 geographic locations
These four different vessels are specifically:

- 110-Ft Cutter Unstabilized
- 110-Ft Cutter Stabilized with Fins
- 82-Ft Cutter Unstabilized
- 47-Ft Cutter Unstabilized

The particulars for the four boats are summarized in Figures 1 and 2 as well as Tables 1 and 2. Figure 1 illustrates the underwater hull forms of the three boats used by the Ship Motion Program, SMP-93, to calculate the motions transfer functions. It is to be noted from this figure that the two larger hulls represent essentially normal displacement hulls for which SMP was initially developed whereas the wedge shaped underwater hull of the 47-Ft cutter departs from this basic geometry. It is to be expected that the predicted ship motion results are most accurate for the larger cutters. Further it is similarly to be noted that the accuracy of the ship motion predictions at the highest speed is questionable. Table 2 amplifies on the dimensional and load particulars of these three existing CG boats.

Figure 2 illustrates at the same scale the outboard profile of the three boats and shows the point locations for which the motion predictions were made. The exact scale used in this drawing can be obtained by recognizing that the longitudinal distance between the 110-Ft cutters forward most hull point and the transom is equal to 110 feet. Table 1 further defines the precise locations on the boats for which the calculations were made. It is to be noted in this context that the point locations were chosen to represent as nearly as possible comparable locations on the three boats. Clearly the inevitable differences in these locations on the individual hulls is a matter of the detail arrangement design of the existing vessels and is particularly evident when the 47-Ft cutter is contrasted to the much larger cutters.

The two operating conditions effectively represent the typical low speed operation on station (0 to 5 knots) expected to be employed fully 50% of the time. This at speed condition consists of two slightly different transit to/from the operational area under different levels of operation urgency. Logically, the second operating condition at speed is anticipated to be employed the balance of the time i.e. 50%. Specifically however, these two latter high speed conditions are to be split 15% operations at the maximum sustained speed and 85% at the best economical speed. Effectively therefore there are three rather than two different speed conditions of interests. These speeds thus are expected to be employed respectively 50% (low speed), 42.5% (economical speed), 7.5% (maximum sustained speed). It is therefore also clear that the maximum calm water speed is considered to be used rarely.

The four discreet speeds of the boats are as follows:

Boat Length	Base Steerage	Best Economical Transiting	Max. Sustained Cruising	Max. Calm Water
47-Ft unstab	5	8	22	27
82-Ft unstab	5	8	18	23
110-Ft unstab	5	10	25	30
110-Ft stabilized	5	10	25	30

For practical purposes these sets of operating conditions have been translated into the following grouping of conditions for use in calculating the specific Percent Time of Operation weighted for speed as WPTO in SEP. The speed weighting for each set of speeds employed was 1.0. The low speed results for 0 and 5 knots were thus weighted equally which represents the assumption that low speed operations will be equally likely for all speeds between 0 and 5 knots. Similarly for the economical speed only a single speed was used for each boat as was the case for the high speed. This latter choices correspond to the assumption that there is essentially little or no variation in these operating speeds.

DEVELOPMENT OF LIMITING MOTION VALUES FOR BOATS IN SEP

Pitch and Heave Motions

To repeat, the behavior of the ship or a boat in pitch for the short periods is similar to that for heave i.e. it will tend not to respond to short periods (a fraction of the natural motion period or

equivalently for ship to wave length ratios less than .5) and attain a maximum response at periods which correspond to wave length to ship length ratios from approximately 1 to 2. For boats, the same dynamic response behavior is valid for pitch as for heave over the range of encountered wave lengths/periods, see Appendix C.

Differences in pitch and heave responses between boats in this series in long waves are negligible because for the long periods (waves) the boats will essentially contour the waves and thus experience relatively mild pitch angles and heave values! For example, the non-dimensional transfer functions, which characterize the boats responses to the waves on a per degree of wave slope for pitch and a per foot of wave height basis for heave indicate that at a wave length to boat waterline length of 2, the pitch value is about .5 and the heave is 1 for all three boats in 60 degree bow seas at 8 knots. As the heading comes closer to the head sea case, the heave response remains unchanged though the pitch increases to the wave slope. In effect then in head or near head seas at wave lengths of about 200 feet (6.3 sec period) all three boats will experience a pitch angle equal to the wave slope and heave exactly equal to wave height. This therefore illustrates that the maximum pitch angle that all three boats will encounter in long waves will be on the order of the maximum wave slope of the waves.

The maximum heave that the ship/boat will encounter similarly in long waves will be on the order of the wave height. No amount of design effort that retains a basic monohull type can alter the encountering of the maximum pitch and heave responses associated with long waves. These maximum values are associated with periods of encounters that are long and thus the acceleration forces thereby imposed on the boat and its crew are mild and of no particular significance.

It remains to be defined just what is meant by long waves in the context of the boats under examination. The simple answer to this is to recognize that once the wave lengths are on the order of twice or at the very most three times the waterline length of the ship, the waves are long. In the case of the 110 ft CG boat the long waves are thus about 200 ft long with a corresponding wave period that is about 6.3 seconds. The corresponding periods for long waves for the 82 ft cutter and the 47 ft boat are about 5.7 and 4.2 seconds respectively. It is therefore certain that when these CG boats will experience breaking waves for these "long" waves these boats will experience the maximum wave slope as they contour these waves.

The maximum wave slope of breaking waves is on the order of 8 degrees. The limiting pitch angle for the CG boats thus will also be on the order of this 8 degrees of pitch since this will be encountered for the longer waves and at these conditions will not represent any difficulties. In fact, the limiting value of PITCH angle that approaches the maximum wave slope is a much more realistic pitch limit than the one suggested by current US Navy design practice for ships of 3 degrees significant. The limiting pitch angles (significant) applicable for the USCG boats thus should be on the order of 8 degrees, the same value currently used for roll angle. A brief review of limiting pitch angles measured during a series of trials with USN & USCG boats and ships suggest that in general even in severe seas maximum values of pitch will be limited to about 6 degrees or less though occasional data suggests values of pitch angles on the order of 8 degrees. The limiting significant pitch angle value considered as part of the base limiting criterion set is thus selected to be 6 degrees.

Roll Angle Limit Criterion

Roll responses in general follow the characteristics of having much longer natural periods for the large ships and disproportionately short periods for boats. It is the requirement to come up with a safe, large GM that forces the boats to come up with roll periods that are relatively short. The currently applied roll limits for US Navy ships are considered to be appropriate for the design of boats because independent of roll period effects, it is at these levels of roll angles that generally all manner of equipment will certainly start to slide and "fly" about on the vessels unless properly secured. Appendix B in Reference 15 summarizes and documents the roll motion limits on ship operations. Roll motions above the 8 degree significant level result in moderate effects which grow to severe effects by the time 12 degree significant roll levels are obtained.

The 8 degree significant roll limit as currently employed in US Navy design practice is thus retained though it is to be recognized that this tends to restrict boats somewhat prematurely because they will in general tend to roll rather easily to eight degrees without incurring any particularly severe consequences other than to induce rather substantial Motion Induced Fatigue. The roll limit as well as the Motion Induced Fatigue comments are based on experience with 50-Ft US Navy Swift boats, 82-Ft & 95-Ft USCG boats on Market Time patrols off South Vietnam during the late 60's and early 70's and trials in the late 70's.

Wetness and Slamming

The initial set of wetness and slamming criteria suggested in the Statement of Work as measured at the bridge helm station, was that a Slamming and wetness frequency of 20/hr was to be considered. The wetness criteria suggested was accepted and used without alteration as part of the base criteria set for this boat study. The acceptable slamming frequency was increased to 30 per hour on the basis of previous trials with a 50-Ft Navy Swift boat. This level of slamming was found to be acceptable. In fact at times even much higher slamming frequencies were found to be acceptable though this varied very much on the kinds of seas encountered.

Vertical Accelerations

The standard US Navy design practice vertical acceleration criteria, suggested in the Statement of Work was retained without modification. It is to be recognized that a distinction needs to be made here between the vertical accelerations that correspond to rigid body motions as predicted in SMP-93 and the combination of rigid body motions and slamming impact accelerations. These latter impact accelerations are not predicted by SMP and are not considered at all in the development of the seakeeping criteria with the exception that the incidence of slamming is calculated. The impact accelerations associated with slamming are beyond the scope of the capabilities of SMP. All acceleration data refer to the rigid body responses of the hull but ignore impact accelerations resulting from slamming.

Long term seakeeping experimental results were examined from the TAGOS monohull ships which tend to perform their primary mission task at very low speed in near head seas. W.L Thomas et al in Reference 10 reported results from a detailed examination of these very extensive ship motion/crew performance evolutions. The analysis of several successive 80 plus day deployments worth of the round the clock, month after month ship motion data and associated crew performance

questionnaires led to the following final vertical acceleration limiting criteria for these towed array retrieval and deployment operations. The limiting criteria values were established for three degradation levels of vertical accelerations:

<u>Degradation</u>	<u>Vert. Acceleration</u>
None/Slight	up to 0.1 g Significant Amplitude
Moderate	0.1 to 0.15 g
Severe	> 0.15 g

These results clearly are substantially lower than the conventionally employed limiting design value of 0.4g. The apparently limiting vertical acceleration values determined by Thomas et. al. in Reference 10 thus label all vertical acceleration levels above .15 g as SEVERE. This however does not explicitly indicate whether the vertical accelerations on the back deck were excessive to the point that operations were limited by "severe" levels of these accelerations. As operations on the ship are performed under ship motion conditions that correspond to these severe situations, the degree of impairment of the crew increases. Of concern for the CG boat operations is at what level will "severe" turn into "dangerous" or "virtually impossible".

Following several debriefings of the crews by the first author it was further established that in none of the recorded cases did these crews indicate that they had experienced unacceptable mission limiting values of ship motions. Thus despite measurements of significant vertical accelerations on the order of .43 g's with peak values of vertical stern accelerations of .87 g's, in no case did they report in the post deployment debriefings that they had experienced unacceptable ship motions. Similarly, these highly experienced crews did not complain under these limiting conditions of excessive MSI.

It is also important to note that in none of these measurements did the significant vertical acceleration levels at the stern exceed .5 g's. The possibility of the crew thus being lifted off the stern deck while working there, due to extreme vertical accelerations therefore did not arise. Thus on the basis of these post deployment debriefings of the crews it is considered that the severe levels of vertical accelerations should be modified as follows:

Vertical Acceleration Limits
for back deck operations
and Pilot House

<u>Degradation</u>	<u>Vert. Acceleration</u>
None/Slight	up to 0.1 g Significant Amplitude
Moderate	0.1 to 0.15 g "
Severe	0.15 to .4 g's "
Limiting	0.4 to .5 g's "
Unacceptable	> 0.5 g (lift off) "

Lateral Accelerations/LFE

The lateral accelerations (in earth coordinates) limitations of .2 g's suggested in the Statement of Work were accepted without revision. However, measurements of the lateral force estimator or the transverse acceleration parallel to the deck limitation as recorded concurrently with the limiting vertical accelerations of 0.2 g's on the TAGOS monohulls were also adopted as a part of the base criteria set.

MII Predictions/Limitations

MII's represent the mechanical interference of ship or boat motions on the personal stability of the crew. Whenever the ship motion induced inertial forces combine to cause a loss of balance, a slide or a lift off, an MII has occurred. The consequence of a particular MII is of course the basic measure of just how important this crew mobility and work limiting event is.

The expressions which predict the occurrence of either a sliding or tipping MII's are essentially the same. They are simple functions of the horizontal and normal accelerations or forces in the ship system and two types of coefficients, friction and tipping. In the ship system the forces are parallel and perpendicular to the ship deck. The horizontal forces are composed of the lateral and the longitudinal accelerations whereas the normal forces are composed of the vertical accelerations including g. In the case of sliding, the occurrence or non-occurrence of the sliding event depends entirely on the balance between the product of the coefficient of friction times the force normal to the deck and the horizontal force acting on the crew. In the case of tipping, the coefficient of friction is replaced by the tipping coefficient of the crew member.

It turns out that the practical range of the coefficient of friction between shoes and decks results in this being much larger than the tipping coefficient. The tipping coefficient of course includes such variations as the differences as a result of stances and body cg etc. Yet the range of tipping coefficients is much lower than the coefficient of friction - as long as the deck is not wet or ice covered or otherwise unusually slick. A slick, wet tiled floor thus would produce sliding before tipping. Thus in general tipping will occur before sliding simply because the tipping coefficient is lower than the coefficient of friction. The lift off due to excessive vertical acceleration is similarly practically preceded by the occurrence of excessive tipping or even sliding.

Allowable Tipping MII Frequency and Fatigue

The issue with regard to tipping is just how much of this is tolerable for a particular situation. Clearly, tipping can be totally prevented by the crew member completely holding on at all times to some part of the structure of the ship/boat. However, when this is allowed (as part of the design of the boat) then of course the crew members are no longer able to function in their assigned tasks. Thus when it becomes necessary for the crew member to continually hold on, he/she is simply not available to perform work in the classic sense.

In the case of the Coast Guard crews on the 1993 Boat series their primary task when the vessel has arrived at the operational area will include the necessity to launch a small boat and even more importantly at some later time (of limited duration) to retrieve this boat. Retrieval will occur potentially when the crew members are now

substantially more fatigued than when the boat launch operation first occurred.

The fatigue status of the crew at the time that the small boat launching or retrieval is to be performed was not calculated as part of this work. It is therefore pointed out that a critical missing criteria of boat performance not included in the base criteria set. This motion induced fatigue, MIF, status of the crew should be included when such a model becomes available. The motion induced fatigue term regarded as missing in this study is the term which accounts for the work as measured in Kilocalories performed by the crew members during the inevitable self stabilization to cope with the avoidance of Motion Induced Interruptions. This work occurs at the frequencies of the motions of the boat and thus is not accounted for in the present criteria set.

It was considered that the maximum number of MII's per minute suggested in the Statement of Work of 2.1 MII's/minute was a reasonable one for two reasons. First it was considered that the consequence of a tipping MII during the small boat launch/retrieval would not likely result in a serious incident or accident. The consequence of the tipping MII was considered to be a lengthening or delaying but not cancellation of the small boat operation. Secondly, this 2.1 MII's per minute criteria level corresponded to a mean time when the crew member did NOT have to hold on or otherwise shift stance to retain balance of about 30 seconds. The small boat launching/retrieval task would thus be generally uninterrupted for about 30 seconds. Substantial "useful" work by the launch/recovery crew could thus be expected to be performed in a 30 second time frame. Clearly when the mean time of the crew to move about and perform the tasks to launch/retrieve the boat reduces to much shorter times, the total time to complete the launch/retrieval will grow substantially as will in likelihood of incidents/accidents. The value of 2.1 MII's per minute was therefore adopted as part of the base criteria set.

MSI Predictions/Limitations

The MSI procedures of the International Organization for Standardization ISO 2631 part 3 or more accurately, the vertical acceleration standards have not been incorporated into the Seakeeping Criteria Set applied in SEP for this study. Instead the old 1979 vintage Carderock Code 5610 procedure of computing MSI which rests directly on the sinusoidal experimental MSI results has been employed.

It should be noted that the calculation procedure for MSI used represents the application of the O'Hanlon and McCauley (1974) and McCauley (1976) model of MSI as defined by the source code shown in Table D-1. This model for predicting motion sickness incidence relates MSI to the amplitude, frequency, and duration of crew exposure to vertical acceleration of the vessel where these vessel motions are sinusoidal. Further, this MSI model applies only to when the MSI is defined to be strictly the vomiting of the subjects. The Carderock application of the O'Hanlon and McCauley MSI theory however interprets the MSI to correspond to whenever the subjects had declared themselves to be motion sick as per sea trial results with a CG crew in Reference 2. Further, the actual nonsinusoidal vertical accelerations experienced by the crew at sea are represented by the rms value and the associated modal period of the acceleration spectra rather than the 1/3 octave band distribution of the vertical accelerations.

Figure 5 was taken from a slide presentation by Kvaerner Fjellstrand shipyard staff to the NATO IEG 6 Subgroup 5 in Norway during April of 1993. This figure illustrates the general format of the ISO 2631 limiting acceleration levels. The relative location in the frequency domain is shown for the three applicable ranges of acceleration limits:

- a) the low frequency "severe discomfort boundaries" range,
- b) the intermediate frequency range which represents the acceleration levels associated with walking or running subjects and
- c) the high frequency fatigue-decreased proficiency boundaries.

These Carderock MSI predictions were made based on the rms vertical accelerations, the associated modal period of the peak of the acceleration spectra, and finally the crews total exposure time to the acceleration levels. It is to be noted that unlike the new MII criteria expressions, the predicted MSI is a function of only a single ship motion variable and its modal period. The remaining ship motions such as roll etc only come into play with the MSI when off centerline positions are considered. Table D-1 of Appendix D documents the specific MSI calculation procedure employed. In effect, the MSI prediction tool essentially is a complex frequency dependent vertical acceleration limit similar to the ISO 2631 part 3 standard though more sensitive to the frequency of the accelerations in the range of boat responses.

The decision was made to employ the old Carderock procedure for the direct calculation of the crews motion impediment due to motion sickness. This choice of techniques was made for three reasons:

1. The limiting criteria should relate if at all possible on the Incidence of Degrading Events rather than the underlying ship motions,
2. A comparison between the observed and predicted MSI's using the Carderock procedure on 1992 ship motion/MSI data from the Naval Biodynamics Laboratory MII experiments and the 1/3 octave band center frequency technique and g limits associated with the ISO 2631-3 standard.
3. Comparisons of the 1/3 octave band techniques & the Carderock procedure with ISO 2631-3 g levels as applied to the worst predicted vertical acceleration responses at the low speed, economical speed and high speed conditions for the 93 Series USCG boats.

Comparison between Predicted and Observed MSI

The comparison of the experimental MSI data taken from the 1 hour duration 1992 MII experiments are shown in the lowest frame of Figure 6. It is to be noted that the subjects underwent testing for MII verification for 1 hour each in this same simulator in which the initial MSI experiments had been performed. The 8 hour, 2 hour, 1 hour and 30 minute exposure time limiting "severe discomfort boundary" curves are also shown in Figure 6. These boundary values correspond to an MSI incident rate of 10%. It is noted that unlike for Figure 5 which shows the frequencies up to 20 HZ, in Figure 6 the results are shown only up to 1 HZ and thus only for the applicable range of the

severe discomfort curves. The operational speeds of the CG boats are too low to excite rigid body responses at frequencies above 1 HZ.

The application of the 1/3 octave band analysis procedure to the measured vertical accelerations are also shown for the two basic 1 hour drive time histories for the NBDL ship motion simulator. The vertical acceleration results from this octave band analysis of the simulator acceleration spectra are shown as open triangular symbols.

The predicted MSI values using the Carderock RMS/Toe procedure (see Table D-1) for the ship motion simulator labeled as runs LIMA #625 and HOTEL #626 were both equal to 9.4%. The Carderock procedure employed an rms value of 0.06 g and a Toe period of 6.4 seconds. These acceleration values are shown as the darkened triangular symbols.

An examination of the results shown in this lowest frame of Figure 6 indicates that the acceleration levels experienced during the 1992 MII experiments (for 1 hour exposures) were not reached. Thus based on this 1/3 octave band analysis technique the results suggest that the 10% MSI incidence would be expected to be incurred in exposure times somewhat between 2 hours and 8 hours. The Carderock procedure applied to exactly the same vertical acceleration spectra data on the other hand suggests that the 10% MSI incidence should be expected to occur somewhere between 1 and 2 hours. It was reported that the actual observed MSI for the LIMA conditions was about 16 percent whereas the HOTEL conditions resulted in a 32% MSI incident frequency. Thus clearly neither of the techniques result in the correct observed answer and both substantially understate the expected MSI. Either technique tends to underpredict the severity of the % MSI to be expected when 10% MSI is calculated. This same, substantial underprediction of the actual incidence of MSI was also observed during the 1980 sea trials with the USCG's 140 boat and 1979 side-by-side Swath, Hamilton Class and 95-Ft patrol boat trials.

Based on these comparisons between experimental data and predicted data using the two MSI or crew comfort criteria it has been concluded that the extra complexity inherent in the application of the ISO procedures (Part 3 of ISO 2631) are not warranted by the accuracy of the predictions.

Worst Vertical Acceleration Comparisons

The worst vertical acceleration data computed with SMP for the three unstabilized boats operating at low speed, economical speed, and the high or maximum sustained cruising speeds in short crested seas of 2.62 ft significant wave height with modal periods ranging from 5 to 17 seconds. These acceleration calculations were made for three point locations on each boat i.e. the pilot house, the boat launching/retrieval station, and what might be called the "crew rest locations" in the berthing area. These data were used to further evaluate the two different crew comfort calculation procedures.

The 1/3 octave band analysis procedure for the ISO standard 2631-3 and the Carderock procedure were applied to these "worst" cases. These corresponded to the results from the worst heading and worst locations onboard the three boats of the '93 Series. The worst location was the berthing area.

At low speed, the 82-Ft cutter appeared to be worse than either of the other two cutters using either technique. At the economical speed the same pattern prevails with the 47-Ft cutter showing the least MSI or crew discomfort for either technique. At the highest speed the 110-Ft cutter is the best though the 47-Ft is inconclusive based on the 1/3

octave technique. The Carderock total acceleration technique on the other hand indicates that at this highest speed, the 47-Ft cutter would be the worst.

The results of this worst acceleration comparison between the two techniques do not clearly favor either technique though there is a better distinction between boats using the 1/3 octave band analysis technique. The other difference between the techniques is that the total acceleration procedure of Carderock will always predict a higher level of discomfort or MSI than will the 1/3 octave band procedure. Since both techniques already underpredict the severity of the MSI incidence, it is the simpler Carderock procedure which is considered to be better for application in the Seakeeping Performance calculations.

MSI Criteria Selection

The initial statement of work suggested two MSI criteria levels (identified as levels 3 and 4 in the tabulation below) as well as a Whole Body Vibration Safety Limit as per ISO 2631. Since the boat responses even at the highest speeds did not occur in the range of the frequencies for which the ISO 2631 Whole Body Vibration Safety limits apply this attempt to impose essentially some recognized fatigue-decreased proficiency boundaries on the boat operation criteria failed. It is to be noted that the 2631 standard unfortunately does not address the crew's motion induced fatigue resulting from their self stabilizing work to prevent motion induced interruptions. This MIF would most definitely apply to the crew and induce fatigue - decreased proficiencies.

In determining a practical range of acceptable MSI criteria to the CG boat operations the 8 hour crew exposure requirement to motions cited in the Statement of Work was considered as the most stringent ISO 2631-3 or severe crew discomfort limit. This extremely tight MSI or crew comfort is identified as level 1 in the tabulation below. Criteria level 3 for the 30 minute "Motion Sickness Vibration Limit per ISO 2631-3 was replaced by the MSI criteria level found to be just barely acceptable for the performance of the MII experiments in 1992 at NBDL. This MSI frequency criteria corresponded to slightly less than 10% predicted for a 1 hour exposure or alternatively to 5% for 30 minutes. The range of possible MSI criteria is therefore summarized in the tabulation below:

MSI Criteria Level

1.	8 hr Fatigue -> 8 hr with only 10% MSI	acceptable
2.	30 min use MORE Stringent 5% MSI	"
3.	30 min use 2631-3 standard .102 g	"
4.	240 min with 50% MSI	"

It was decided to translate these various MSI levels to a common rms g level experienced with the worst motion sickness cases for the three boats at 5 second. Table D-3 of Appendix D summarized these translations of MSI frequency and period as well as period of crew exposure into common rms g levels using the MSI theory of McCauley et al in Reference 22 as executed with the simple computer program shown in Table D-1. Thus this translation of the MSI criteria range into the common following 4 hr duration MSI levels:

5 Second Vert. Acc. Period

MSI Criteria Level		RMS Vert Acc	MSI in 4 Hr	MSI in 30 min
1	Most Stringent	0.039	7.9 %	1.1 %
2	Base Criteria	0.065	19.6 %	5.0 %
3	Less Stringent	0.102	35.0 %	14.1 %
4	Least	0.15	50.1 %	27.5 %

Implications of the Limiting Criteria

The boat limiting criteria may be grouped into two sets. The first set tends to result in voluntary speed limiting (reductions) and the second set tends to result in crew limiting events.

When the voluntary speed limiting criteria are violated it will be visibility, vertical accelerations, slam accelerations, and their consequences that will endanger both ship/boat systems and the crew. The crew limiting criteria consist of MSI, MIF (Fatigue), MII (Tipping) as well as the simple criteria of vertical accelerations and motions. When these crew limiting criteria are substantially violated it is likely that crew safety hazards such as an increased crew accident rate will be incurred.

Largely the issue of how much to violate the above criteria is a boat operator decision locally at the time of the operation. In fact, the recognition that the criteria are being violated has not ever been automated and thus the operators must locally make the decision on the basis of observations and "feeling/estimation" of the magnitudes of the limiting criteria. This recognition of the levels of the limiting seakeeping/crew criteria can only change if or when the deploying agency includes techniques for recognizing that the criteria are being violated as part of the boats outfit.

The inclusion of such criteria recognition equipment as part of the basic outfit for the boat could be done easily and with minimal cost. The use and reliability of current acceleration sensors as well as the data collecting/display PC's was clearly demonstrated during the years of the deployments of such units on the US carriers and the TAGOS monohulls. The PC based Active Operator Guidance (AOG) system as currently deployed for example on the USS INDEPENDENCE with active sensors would be such a recognition outfit equipment that can be used to locate the courses and speeds at which the criteria are not violated.

The question as to whether or not the limiting criteria can or should be relaxed without significantly affecting the crew safety or the integrity of the boat systems and what will be the result when they are relaxed individually by say 50% was also examined briefly during this current study. This was done with a pilot study of the sensitivity of the WPTO to various levels of the criteria is included as Appendix F. This indicates that, in general the criteria are selected such that little if any gain in operability is to be gained when they are exceeded by as much as 50%. Of course the consequence on accident rate etc can not to be deduced from that study.

Base Seakeeping Criteria Set

Despite the philosophic goal of constructing a seakeeping criteria set based entirely on complex, degrading event criteria such as MII's, MSI's, slamming, wetness, and the related propeller emergence rather than simple criteria based on individual motion components such as the roll, pitch etc, a mixed set of simple and complex limiting criteria were selected for this USCG Boat study. The state-of-the-art of available models for the complex degrading event criteria limited the final selection, see References 16 through 23. Further, it is to be recognized that even out of this mixed set of criteria there are clearly some missing criteria. These missing criteria include, motion induced fatigue or MIF, the lift off events associated with MII's and excessive vertical accelerations as well as longitudinal accelerations.¹ A single base set of limiting criteria was employed. This applied base set of ship motion criteria or limiting events used was as follows:

Roll	R	8.0 Deg Sig.Amp.
Pitch	P	6.0 Deg Sig.Amp.
Wetness.	W	20 per hour
Slamming	S	30 per hour
Acceleration, Vertical	A	0.4 g Sign.Amp.
Lateral acc, earth co-ordinates. LA	LA	0.2 g Sign Amp.
LFE, lateral force estimator . .	LFE	0.2 g Sign.Amp.
Tip.	TIP	2.1 Tipping's/Min
MSI.	MSI	5% in 30 Min Exposure

WPTO Sensitivity to Criteria Variation

The object of this 1993 CG Boat Series study was to determine a basic set of seakeeping criteria by which the seakeeping merits of candidate boats for a particular mission can be judged. Attainment of the objective involved a detailed operability prediction process for which this base criteria set was established and then applied. It is to be recognized that the seakeeping criteria represent currently the weakest link in the logical chain in this operability prediction process as used as standard practice in the US Navy ship design cycle.

Tables 8 through 20 are typical edited outputs from the SEP program and they are presented for illustrative purposes only. Tables 8 and 9 provide an example for the 82-ft cutter of the influence of location on the limiting seakeeping factors (criteria) and on the PTO's. Tables 10 through 12 similarly provide the influence of location effect data on limiting wave heights for the modal wave periods and the associated limiting criteria. Table 13 provides an example for the 47-ft cutter of the same influence of location on the limiting seakeeping criteria. Tables 14 and 15 provide the same data for the unstabilized and stabilized 110-ft cutters. Tables 16 and 17 provide for the 82-ft cutter examples of the effect in variations in the levels of the roll criteria on WPTO at low and high speeds. Tables 18 through 20 provide similar data for the variations in MII criteria levels.

1. A.E. Baitis, F.D. Holcombe, P. Crossland, "1991-1992 Motion Induced Interruption, MII Experiments at the Naval Biodynamics Laboratory" CRDKSWC-HD-1423-01 July 1993, draft.

A limited study served as a final quality check on the accuracy of the base seakeeping criteria set in predicting the WPTO i.e. WPTO sensitivity to seakeeping criteria variations. This study in turn started by examining in some detail the motion criteria that most significantly affects boat performance and that can be changed as part of the design - roll motion. The limiting criteria that are identified in this roll criteria sensitivity examination were then similarly further examined. The detailed results and figures of this quality check are presented in Appendix F.

The accuracy of the roll motion criteria selected in this study or rather left unaltered from current US Navy ship design practice was established by examining the sensitivity of the figure of merit measure, WPTO, to really substantial changes in the value of the roll criteria. Specifically, it was decided to examine the base criteria sets significant roll value and a full + and - 50% variation of this value. In other words the base criteria set was employed and the computational runs were repeated for the following values of the roll criteria:

- 4 degrees of significant roll
- 8 degrees of significant roll - base value
- 12 degrees of significant roll

It is to be recognized that the logic implemented in the Seakeeping Evaluation Program, SEP, considers the operability of a ship or boat to be limited when any one of the seakeeping factors or criteria are violated or exceeded. In fact, it is the first criteria that limits ship or boat operability at any particular ship speed and heading in a specific seaway. This first criteria that limits is designated by SEP as the limiting seakeeping factor. Thus it is also to be recognized that different seakeeping criteria can and do limit the operability of a vessel at various operating conditions or locations on the vessel.

When a given limiting seakeeping factor or criteria is lowered there are two outcomes. These outcomes are changes in the overall WPTO and changes in the identity of the new limiting criteria. In case of the operability measure WPTO, the change may range from negligible small to a significant change. If this change is small it follows that the accuracy of the varied criteria is adequate since its value does not particularly affect the overall payoff function, the WPTO. Conversely, if the WPTO change is large for a change in the value of the limiting criteria then the accuracy of the limiting criteria is very important.

Typical WPTO results of the roll motion set of sensitivity calculations were obtained for the 82-Ft cutter operating at low speed in the Atlantic and Gulf of Mexico using the annual wave data. These data are presented in Appendix F, part a of Figure F-1. The graph of WPTO consist for each location identified by the gridpoint as three vertical bars. These correspond respectively to the WPTO for the roll criteria at 4, 8, and 12 degrees.

It is clear from these results that the WPTO's reach essentially a nearly stable value at each of the geographic locations once the 8 degree significant roll value is attained. It is thus concluded that the 8 degree significant roll criteria represents a satisfactory roll criteria value. Relaxing this criteria to accept the much larger 12 degree significant roll limit simply does not result in any appreciable gain in the boats operability.

Once the operational area shifts to the Pacific and the speed increases to the high speed as illustrated in part b of Figure F-1 the

differences in operability resulting from the use of 4, 8, and 12 degree criteria levels shrink very substantially. However, the basic trend of the operations in the Atlantic which indicates that the 8 degree roll limit is the lowest acceptable roll criteria are still supported in the Fall Pacific data. It is apparent that in the geographic location with the mildest sea conditions in the CG wave data base, P-625 off shore of southern California, roll motion is of lesser importance and the differences in the WPTO as a function of the roll criteria levels virtually disappear.

The roll criteria variation results identified the MII of tipping as the most important, frequently limiting criteria whereas MSI and slamming were respectively less important.

The MII criteria variation results indicate that the base MII value is an acceptable value because there is little operability to be gained once this value is selected. Relaxing the MII criteria to permit as many as 6 tips per minute which corresponds to an expected time between tipping MII's of only 10 seconds simply does not add at the low speed though some gains are registered at the higher speeds.

There is essentially no effect on WPTO at lower speed when the acceptable MII's are relaxed beyond the base line value, the only difference observed is that the actual limiting criteria change in importance. As the MII criteria value is relaxed from the most severe once the importance of the tipping decreases as roll begins to increase and then slamming increases in importance. The same general conclusion is valid for operations at the economical speed, although here the roll does become a limiting criteria, being instead by the lateral force estimator which is the acceleration in the plane of the deck largely induced by roll angle.

The WPTO results indicate that at the lower speed there are substantial gains to be made when the MSI level is relaxed from the most restrictive to the least restrictive level. However, it is also clear that the gains in operability to be made by relaxing the criteria beyond the base criteria value are small. This same trend is reinforced by the results at the higher speeds. It is therefore concluded that the base MSI criteria value is a rational one to employ. This is particularly considered to be valid because this MSI criteria value corresponds to a level found to be just acceptable during 1992 Experiments with US Navy enlisted Human Subject Volunteers. These subject are representative of the crews of US Navy and US Coast Guard vessels conducting minor physical tasks for one hour durations.

The slamming criteria variation (F-3) indicated that even the most restrictive criteria value of allowing only 15 slams per hour or alternatively 1 slam every four minutes do not alter the WPTO. It is thus concluded that the particular value of the slamming criteria for boats is not a particularly useful discriminator of boat operability. Slamming remains the least most important limiting criteria identified by the variations of the roll criteria. Tables 21 and 22 show the seasonal weighted percent operability results of all boats.

Boat Launch/Retrieval Operability Capability

The base criteria set was employed in SEP along with the assumption that the boats were permitted to seek the best course and speed at the boat launch/retrieval speed of 5 knots. Further it was assumed that the operator/helmsman is capable of maintaining the heading relative to the waves to be restricted to within 30 degrees off the stern. No thought or restriction was given as to how the operator managed to get to the site in the seas. Instead, only the possibility

of being able to launch or retrieve the boat in seas at the various wave height bands was considered. These limited results are summarized in Tables 23 and 24 for all four of the boat combinations. Appendix G contains the USCG statement of work for 80 foot WPB capability replacement seakeeping base line and some selection criteria recommendations.

The results of Table 23 illustrate the boat launching and retrieval capability at two specific locations i.e. grid point G-401 and G-610. The Table presents for each .5 meter wave height band up to a height of 6.5 meters the percent time of occurrence of the waves and then the percent time of operation for each of the four boats. Given that the design goal is to be capable of launching and retrieving the boat in 2.5 meter seas 100% of the time it is evident that none of the boats meet this goal at the Gulf location though the stabilized 110-Ft cutter provides 100% operability in this restricted sense in seas up to 2 meters. By the time the 2 to 2.5 meter band is reached this stabilized cutter - if it could in fact operate at such a low speed with adequate directional control, the percent operability in this band drops to 98%.

The unstabilized 110-Ft cutter retains 91% operability in the 1.5 to 2 meter wave height band and retains 96% operability in the 2 to 2.5 meter wave height band.

The 82-Ft cutter retains its 100% operability only through the .5 to 1 meter band and then drops operability in the next higher bands to 80, 50 and 85% respectively.

The 47-Ft cutter retains its 100% boat launching or retrieval capability only in the wave height band from 0 to .5 meters. It then loses its capability until by the time the 2 to 2.5 meter wave height band is reached it retains a 69% operability. Its cumulative operability by this time has dropped to 81 percent.

The 82-Ft cutter's cumulative PTO by the time the 2 to 2.5 meter wave height band is reached has dropped to 99%. Clearly then the 82-Ft cutter will retain a 90% operability in seas up to 2.5 meters whereas as the 110-Ft cutter stabilized or unstabilized will provide nearly 100 % boat launch and retrieval operability. The cumulative percent operability which the results attain represent a simple summary of the boats capabilities in the restricted sense.

A similar review of the boats operating in the Pacific grid point P-610 yield substantial improvements since the waves are so much longer.

Finally, Table 24 summarized the cumulative percent operability for all 10 of the CG operational areas. It is to be noted that this measure clearly distinguishes between the boats though it certainly leaves open the question as to how the boats are to reach their operational location.

BASE CRITERIA SET RESULTS: WPTO

Individual Sets of WPTO Data

Five basic sets of figures illustrate the weighted percentage time of operation, WPTO, for the four boat combinations for the single base set of seakeeping criteria.

Operational Location Effect

The first data set, consisting of Figures 7 - 9 present for each of the 10 wave data locations the WPTO based on the annual wave data. The locations are arranged in north to south order first on the US coast of the Atlantic/Gulf of Mexico and then on the Pacific coast. For each wave location the results for the boats are arranged from left to right in order of increasing boat size with the roll stabilized 110-Ft cutter occupying the position of the largest, most capable boat.

At the two lower speed ranges of operations the order of the capability of the boats is the same as for the length or size of the vessel at each location. At the highest speed, which represents also the least accurate boat motion predictions, the 82-Ft boat appears to look very good in comparison to the 110-Ft cutter in the Pacific operational areas. It is to be noted in this context that for the highest operational speeds the differences between the speed capability of the three vessels is by far the largest. The 82-Ft cutter has by far the lowest speed and thus would tend to "contour" the waves more readily than would be the case for the faster 47-Ft and 110-Ft cutters. The "good" performance of the 82-Ft cutter at the highest speed is therefore the result of this boat having the lowest Maximum Sustained speed rather than some other design feature.

The distinction between the boats as measured by operability is most noticeable at the lowest speed and for the geographic locations which has the shortest and highest waves. The least distinction is obtained for the location with longest waves.

A clear geographic trend is noticeable with the least operability being in the northern most location and the Gulf of Mexico exhibiting a surprisingly low WPTO particularly for the smallest boat. Clearly in the longer Pacific waves the distinction in performance variation between the boats is minimized.

The second group of figures, Figures 10 - 12 repeats the same data format as for Figures 7 - 9 but now presents the data for the winter season. As expected the data for winter season operabilities are generally lower than for the annual wave data but otherwise mirrors these results.

Roll Stabilization Effects

The effect of roll stabilization on CG boat operability is also illustrated by the WPTO results when they are examined as a function of ship speed. The WPTO results for the low speed incorporate the results from two speeds i.e. 0 knots and 5 knots. Since fins generate their roll quenching forces as a function of speed, with virtually zero force developed at 0 knots and this force growing almost with the square of speed, the 5 knot results do illustrate some benefits of roll stabilization. It is however at the economical speed of 8 to 10 knots that largest benefit of roll stabilization by the fins is noted. As ship speed increases the effects of the fin stabilization reduces as hull damping increases thus the fins contribution to the total roll damping decreases.

The magnitude of the benefits attained by roll stabilization at the economical speed are sufficiently large that the addition of a set of well operating fins would increase the 82-Ft cutters operability in general to equal that of the unstabilized 110-Ft cutter. Clearly this level of operational gain is achieved at a far lower cost by roll

stabilization than by building a much larger boat. The importance of roll stabilization at zero speed as part of the basic design should also be recognized. The use of low speed or zero speed roll stabilization devices such as box keels or bilge keels are thus of value when it is recognized that really significant roll reductions are possible with such devices.

Seasonal Effect on WPTO

The third set of data applicable to the 82-Ft cutter in Figures 13 and 14 expands on the effect of the seasons. The data is arranged by season (winter, spring, summer, fall and annual) for each grid point. Further this data is illustrated only for the low and economical speeds. It is apparent that the seasonal effect is really quite different in the three southernmost Pacific operational areas than in either the Gulf of Mexico or Atlantic Coastal areas. Unlike in the Atlantic or the Gulf of Mexico, the winter season in the Pacific is not the worst season as far as operability is concerned. This factor is considered to be the result of the fact that the waves in the Pacific in winter are rather long and do not induce large roll responses in the boats.

Speed Effect on WPTO

The fourth set of data, Figures 15 - 24, illustrates the speed effect at each grid point for the four boats arranged from left to right in order of increasing length or capability. These data exhibit similar trends to the data of the previous three sets. The distinction between the boats is clearest in the northern most Atlantic location (A-405 and least evident in the mild southernmost Pacific location (P-625).

The fifth data set, Figure 25 - 27, presents the WPTO results for each boat separately in four categories of speeds with the fourth speed category representing the weighted combined result:

Low speed	(0, 5 kts)
Economical Speed	(8 or 10 knots)
High or Maximum Sustained Speed	(22, 18, and 25 knots respectively for the 47-Ft, 82-Ft and 110-Ft boats)
Combined (.5, .425 and .0725)	(Low speed WPTO*.50 + Econ. " WPTO*.425 + High " WPTO*.0725)

CONCLUSIONS

1. In general, boats will tend to operate in long waves relative to their length. As a result a major portion of the time they will tend at the lower speeds (less than 10 knots) to operate by essentially contouring the waves. Their dynamic responses in heave and pitch under these circumstances are not subject to serious changes by design of the hulls. No distinction in these basic ship motion components can thus be expected for differing monohulls.

2. Roll motion is the most significant single component of boat motions that affect operability. Roll due to the short periods of the boat adds strongly into the vertical acceleration forces experienced at off centerline locations on the boat.

3. Only roll motions can be altered with complete confidence and minimal risk as part of the small boat design process and as a result the vessel with the lowest amount of roll and roll related criteria will represent the most successful boat from the seakeeping viewpoint. This assumes that detail design features which minimize the consequence of the other boat motion components such as the pitch and heave related wetness and slamming magnitudes.

4. As noted in published 1982/1983 work by US Navy as well as US and UK private companies in the boat and ship motion stabilization area, substantial, beneficial pitch motion stabilization can be attained with existing conventional components and limited sized machinery with a high degree of confidence.

5. The MII criteria of Tipping is the most limiting criteria.

6. The MII criteria component of "lift off" due to excessive vertical accelerations which exceed 1 g should be incorporated into the criteria model. This criteria represents significant safety concerns to the crew.

7. The other component of the ship motion related crew degradation that was not included in the current study was the Motion Induced Fatigue which for the US Navy destroyers was of only moderate value when operating in Sea State 5 on the flight deck. The fact that the motion periods of the boats are more than three times faster than for the destroyers suggests that this mechanical work load imposed on the crew by the boat motions is NOT negligible and instead is on the order of at least three times greater than for the destroyer. It is this MIF which is also missing from the fatigue standards in ISO 2631 because it extends into the range of boat motions that the crews will experience.

8. The PTO of the four boats clearly distinguishes the boats from one another. The trends are as expected in that WPTO increases with increasing boat length. The smallest boat has the least operability in the operational areas. The greatest distinction between the boats is possible in general for the worst sea conditions.

9. The effect of roll stabilization on PTO is clear and occurs as expected at the lower forward speeds. At 0 speed the fins are ineffective though even by the time speed has increased to 5 knots benefits are to be obtained. The greatest benefits of roll stabilization occur at the Economical Speed. At this speed the difference between the 82-Ft cutter and the unstabilized 110-Ft cutter can be largely closed by providing the 82-Ft boat with fin roll stabilization. Rudder roll stabilization can augment the available roll stabilization from fins.

RECOMMENDATIONS

1. Expand the design specification effort to reduce roll at all speeds including at zero speed.

2. Do not expend energy in reducing the boats heave and pitch or related responses during the initial design/specification part of the boat acquisition cycle except in assuring that details to mitigate slamming impacts and wetness and visibility restrictions.

3. After the first boat is delivered, consider installing and testing a pitch stabilization system to reduced the occurrence and magnitude of vertical accelerations that induce both MSI, MII, and more important MIF. It is to be recognized that during the 1983 full scale experiments with a 42 foot v bottom pleasure boat, these benefits were recognized and experienced by two of the present authors. In short, pitch stabilization is possible at the expense of drag.

4. Insure that the crew can obtain rest while in transit to the operational area such as could be provided by airliner types of reclined seating.

5. Employ the base criteria set for rating the seaworthiness merit of different boats.

6. Expand the base criteria set by resurrecting the Motion Induced Fatigue Model initially developed for the US Navy's FFG-7 in 1982. Include as part of the basic design specifications crew rest facilities such as two or three airliner types of seats instead of berthing facilities that can not be utilized during the mission.

7. Also expand the MII by including the lift off criteria to avoid failing to recognized potentially hazardous boat operating conditions where lift off can occur and crew injuries can easily result.

8. Expand the base criteria set to include the longitudinal acceleration in the plane of the deck, particularly at the higher locations within the boat where these may actually approach the values of vertical accelerations.

9. Initiate MSI coping training for the crew to eliminate MSI as an issue with the boat crews.

10. The inclusion of criteria recognition equipment as part of the basic outfit for the boats is recommended. Such minimal cost equipment can vary from a simple analog type of meter output to the more comprehensive Active Operator Guidance polar graph displays with notebook based PC's.

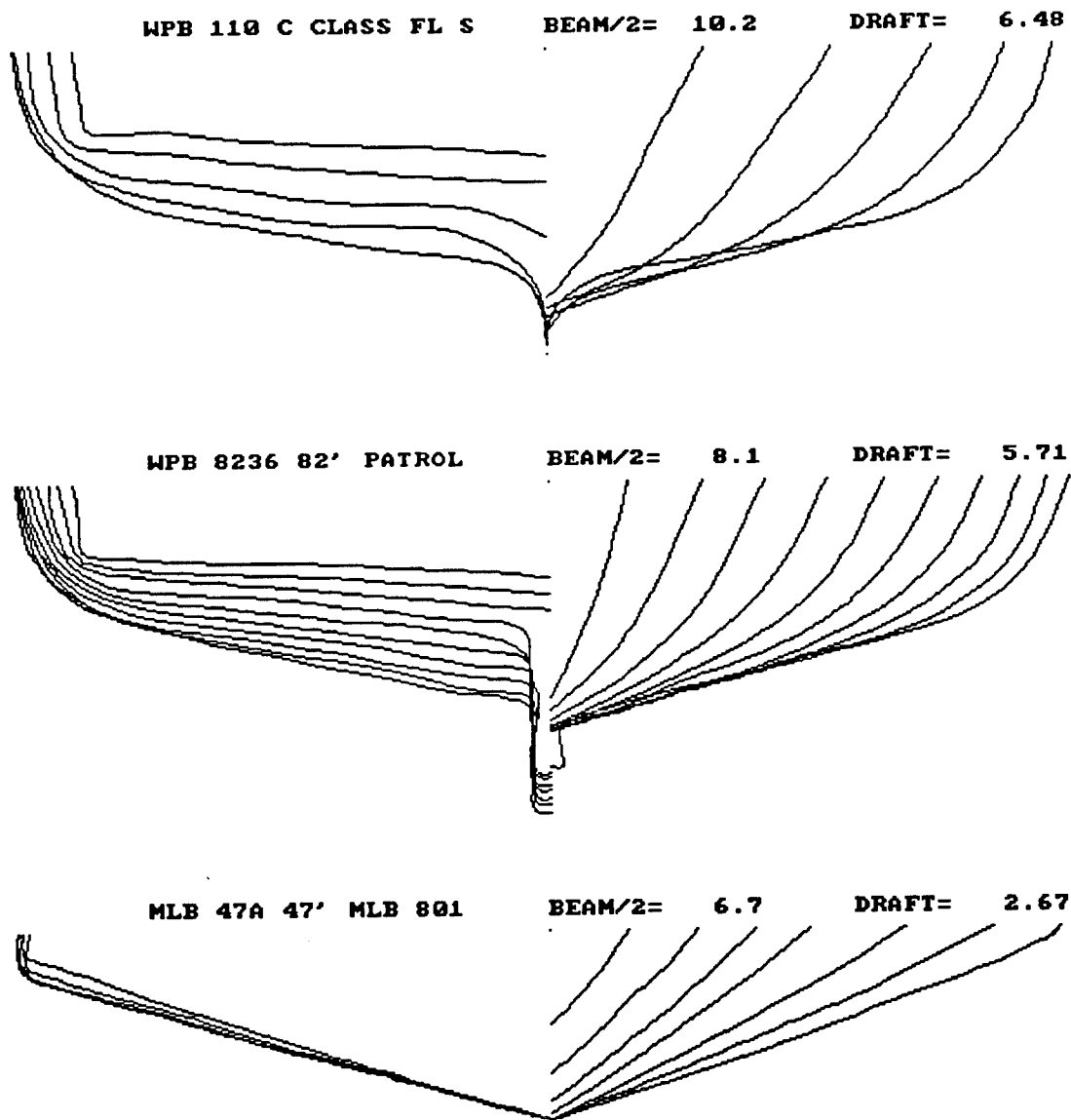
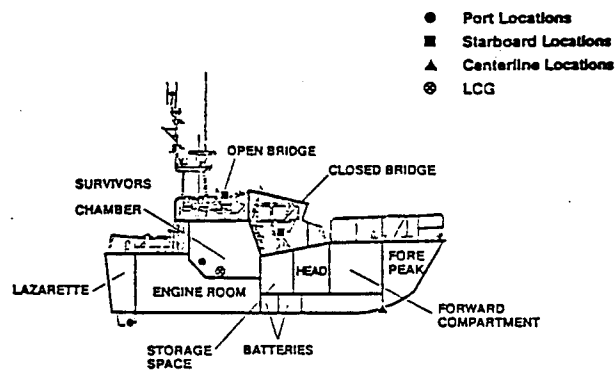
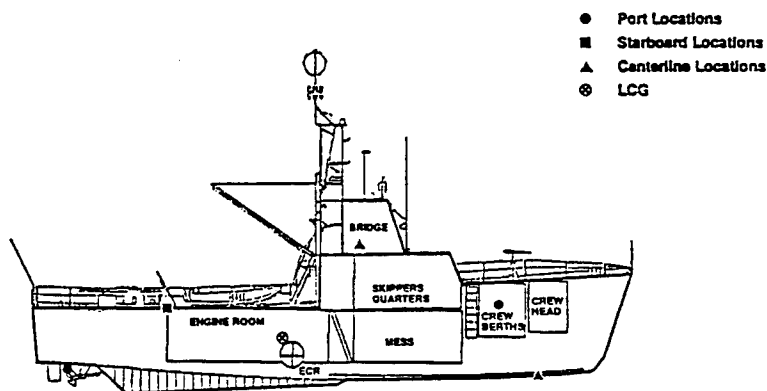


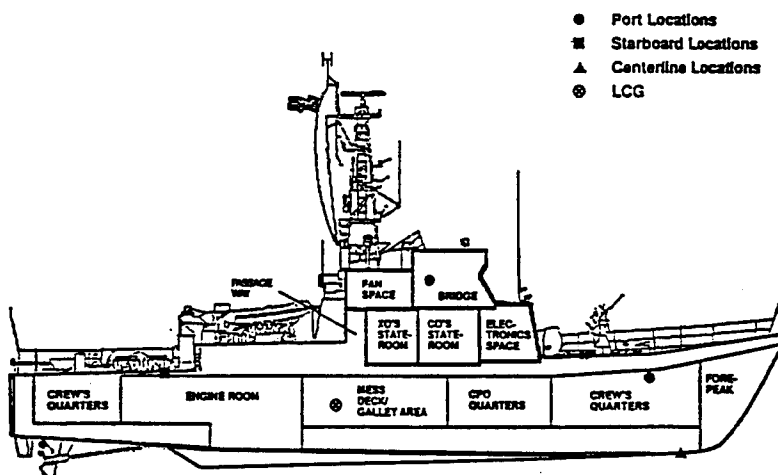
Figure 1 Underwater Hull Forms for 1993 USCG Seakeeping Criteria Boat Series - 47-Ft, 82-Ft and 110-Ft Cutters



OUTBOARD PROFILE OF CG47



OUTBOARD PROFILE OF CG82



OUTBOARD PROFILE OF CG110

Figure 2 Outboard Profile for 47-Ft, 82-Ft and 110-Ft USCG Cutters the 1993 USCG Seakeeping Criteria Boat Series

BUOY LOCATIONS USED IN THE COAST GUARD DATA BASE

	GRID POINT	SUBPROJECTION	LATITUDE	LONGITUDE	NUMBER OF SAMPLES
ATLANTIC	401	4	25.9 N	89.7 W	65534
	402	4	36.9 N	75.7 W	21863
	403	4	30.3 N	80.4 W	13611
	405	4	42.7 N	68.3 W	66070
	409	4	29.3 N	87.5 W	15831
	412	4	38.8 N	74.6 W	16062
PACIFIC	610	6	46.2 N	124.2 W	55106
	611	6	34.9 N	120.9 W	54304
	613	6	38.2 N	123.3 W	55463
	625	6	33.6 N	119.0 W	53936

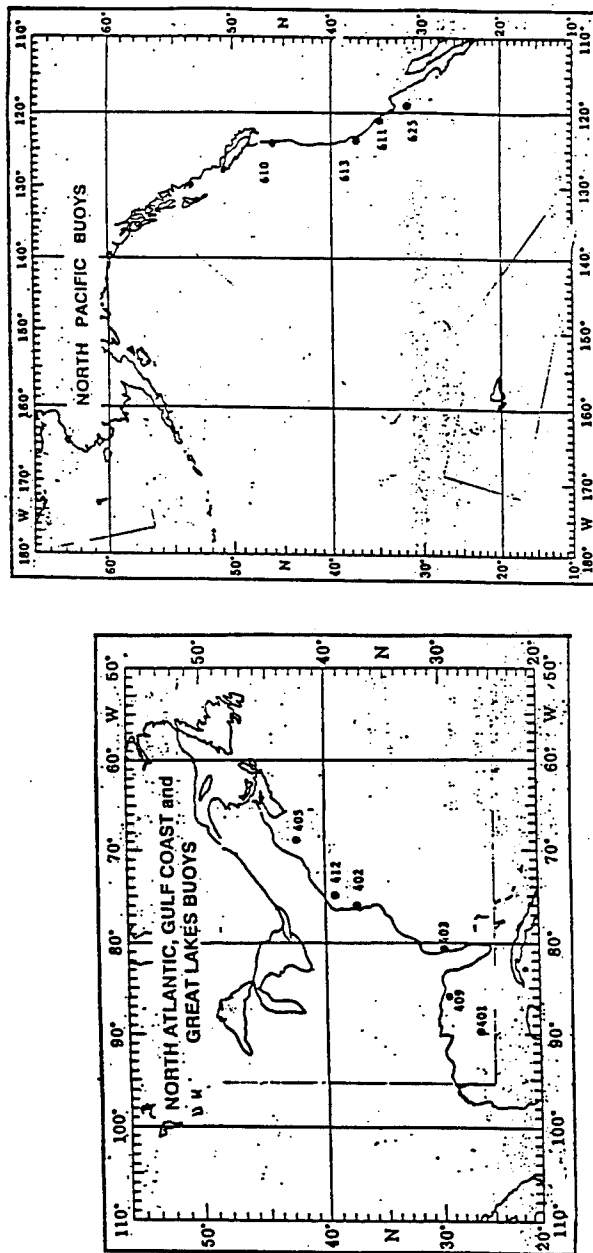
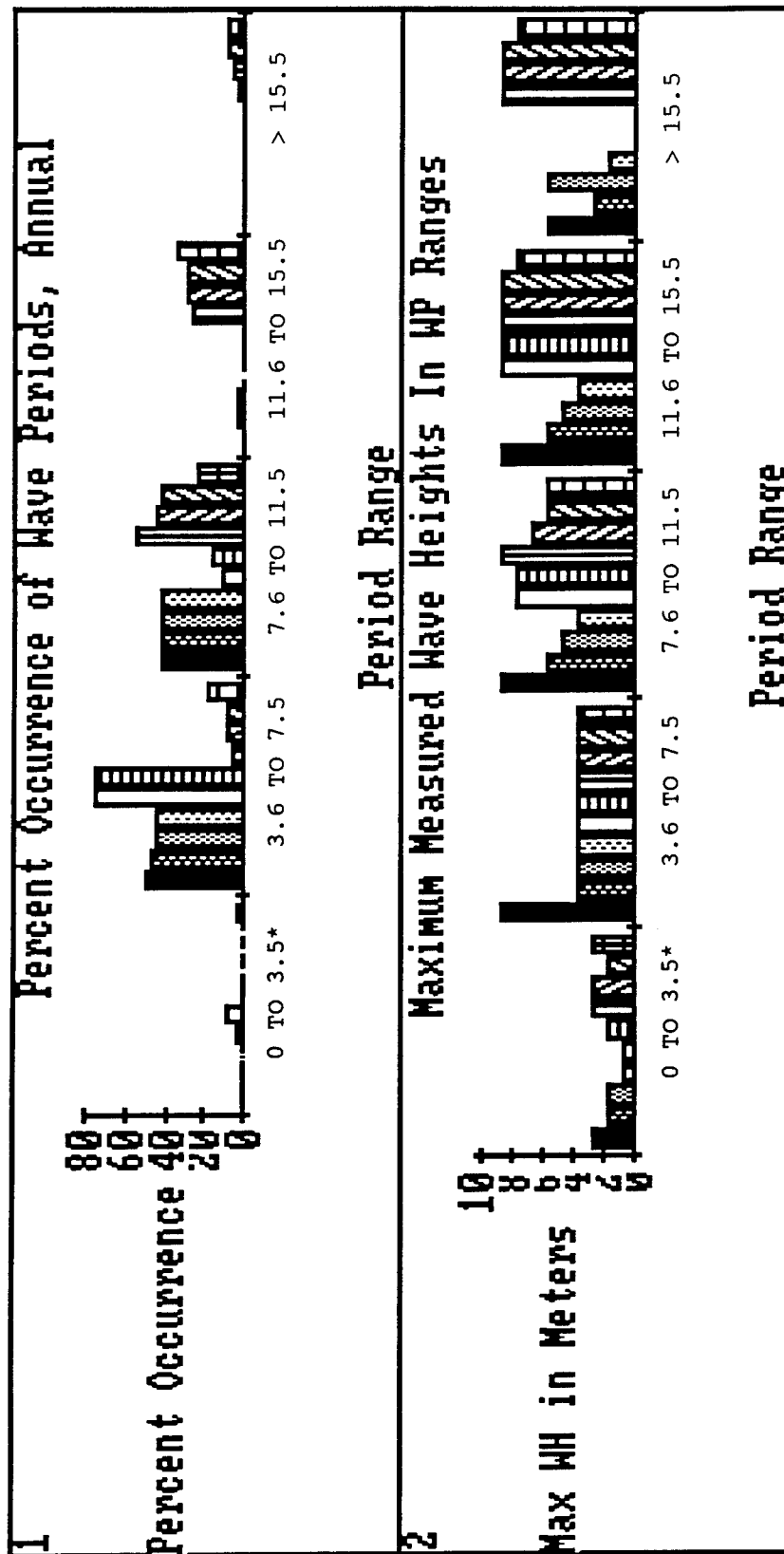


Figure 3 NOAA Buoy Locations for Wave Measurement Statistics Used for 1993 USCG Seakeeping Criteria Boat Series

Figure 4 NOAA Wave Data Used for 1993 USCG Seakeeping Criteria Boat Series - Percent Occurrence of Wave Periods (Annual) and Maximum Measured Wave Heights in the Period Ranges for A-405, A-412, A-402, A-403, G-409, G-401, P-610, P-613, P-611, P-625



* Period range for Pacific Ocean grid points (P-610, P-613, P-611, P-625) are 0 to 6, 6.1 to 7.5, 7.6 to 11.5, 11.6 to 15.5, and greater than 15.5 sec.

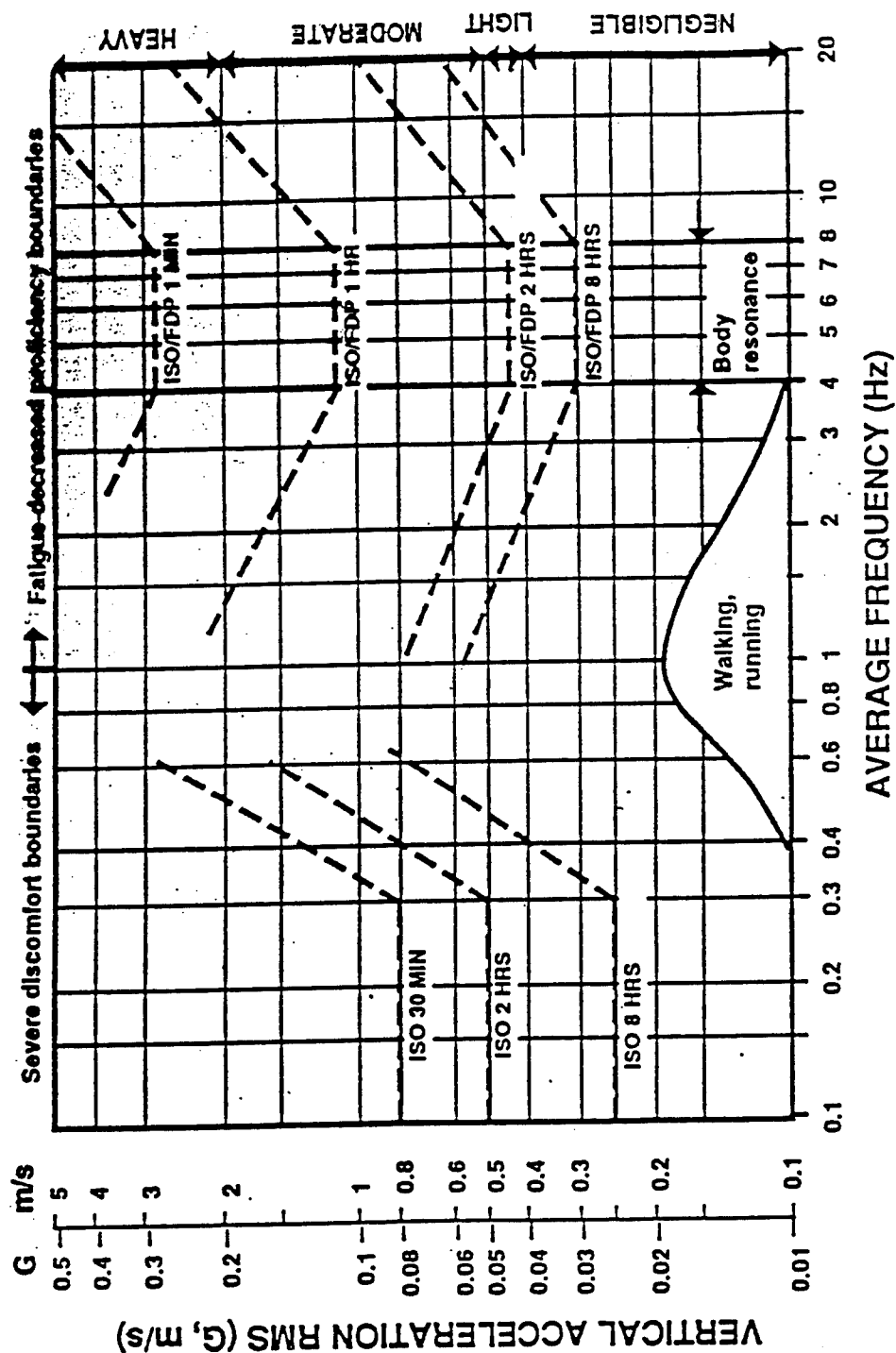
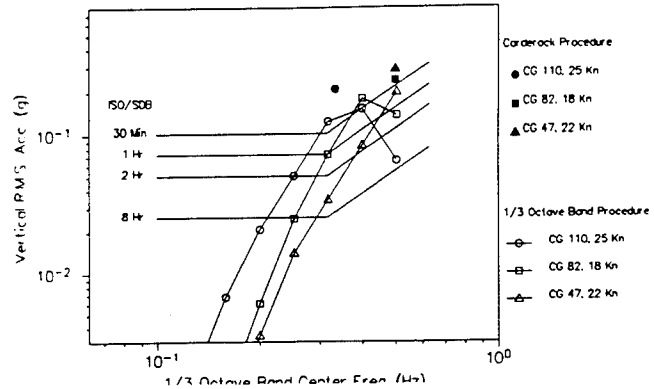


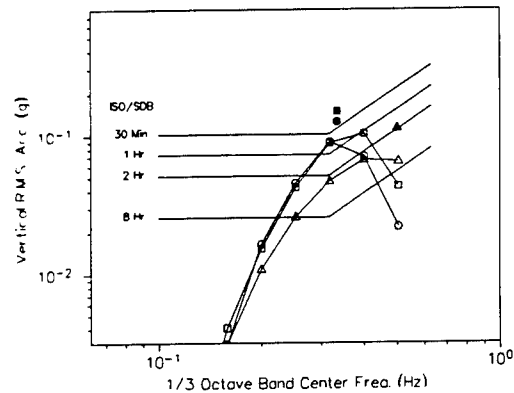
Figure 5 Combined Results for severe discomfort and fatigue - decreased proficiency according to ISO 2631-3. *Figure from Kvaerner Fjellstrand

Predictions of RMS
Vertical Accelerations
of 1993 USCG Boat Series

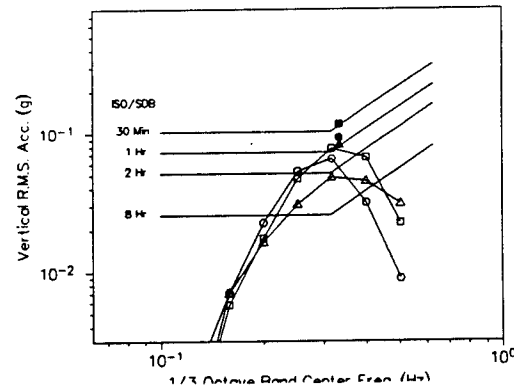
Max Sustained Speed



Economical Speed



Low Speed 5 Knots



1992 NBDL MII Experiments

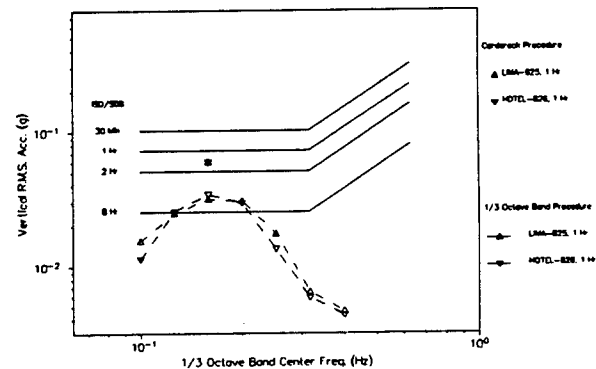


Figure 6 MSI Results Comparison Using 1/3 Octave Band Analysis and Carderock Procedure (Total Acceleration) - ISO 2631-3

47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Low Speed Ops, Annual Wave Data

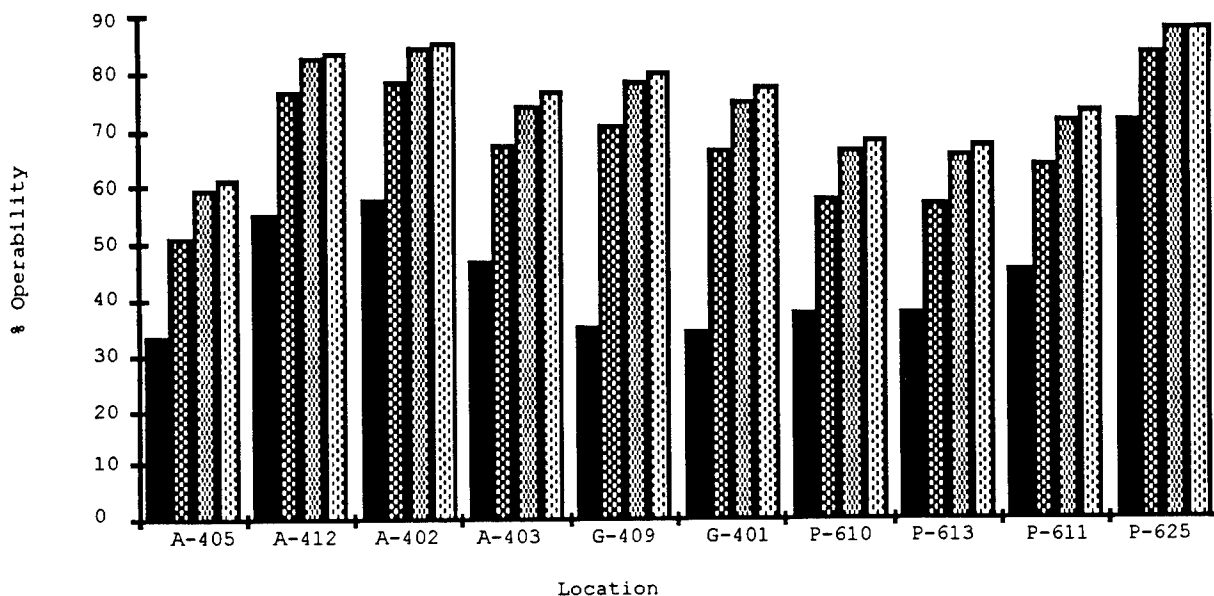


Figure 7 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Low Speed Ops, Annual Wave Data; (File CG1F.grf)

47-Ft,82-Ft,110-Ft Unstab & 110-Ft Stab;Base Criteria Set, Economical Speed Ops, Annual Wave Data

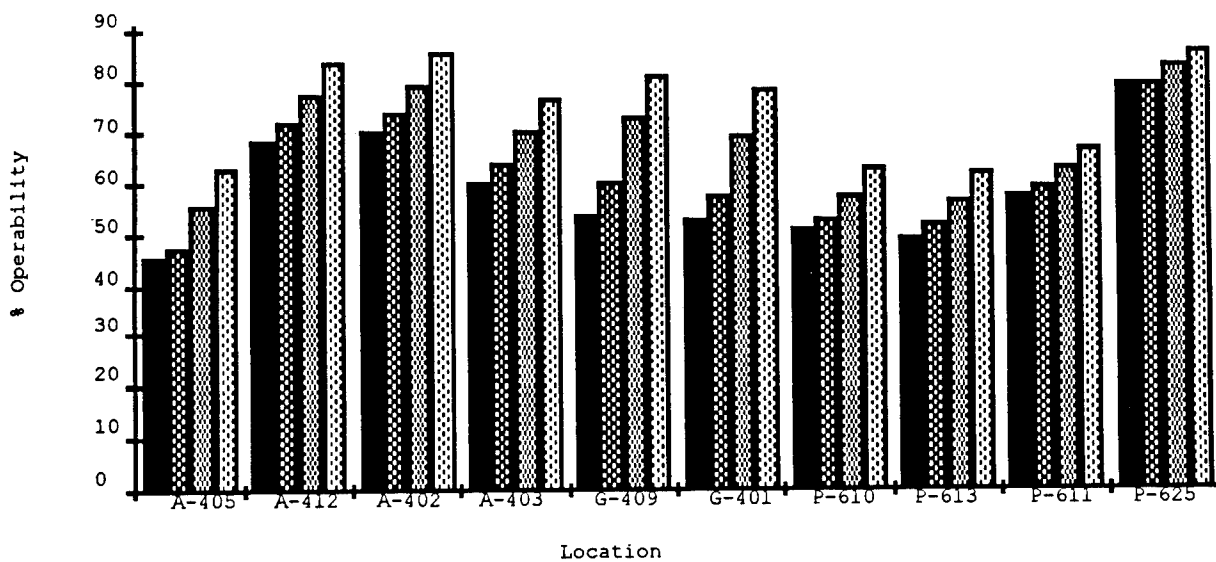


Figure 8 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Economical Speed Ops, Annual Wave Data; (File CG2F.grf)

47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, High Speed Ops, Annual Wave Data

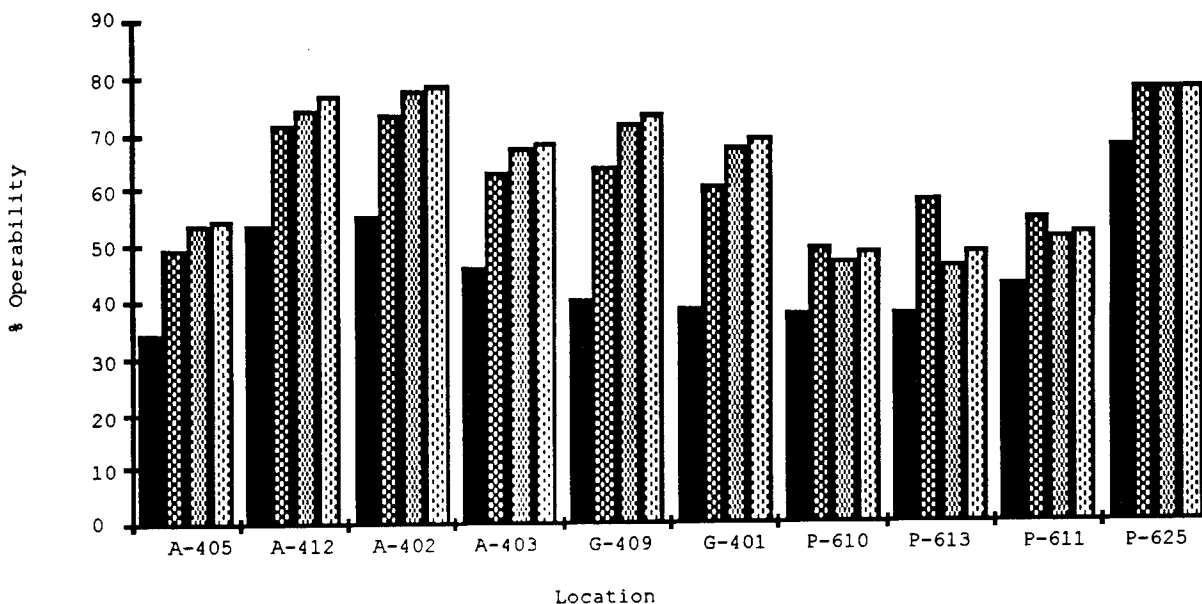


Figure 9 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, High Speed Ops, Annual Wave Data; (File CG3F.grf)

47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Low Speed Ops, Winter Wave Data

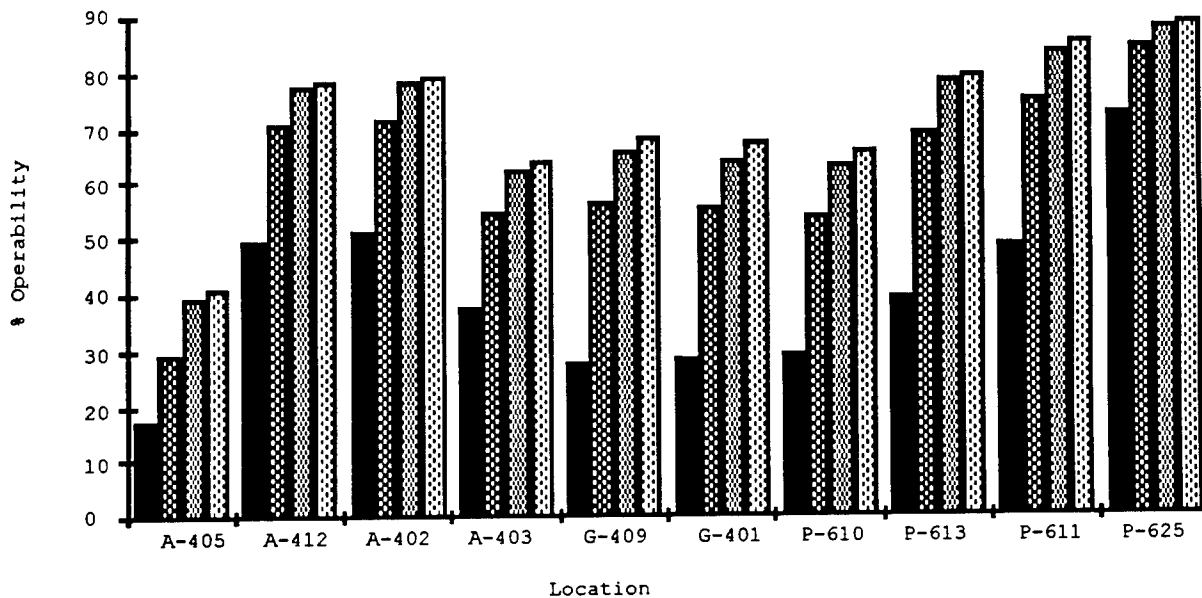


Figure 10 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Low Speed Ops, Winter Wave Data; (File CG4F.grf)

47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Economical Speed Ops, Winter Wave Data

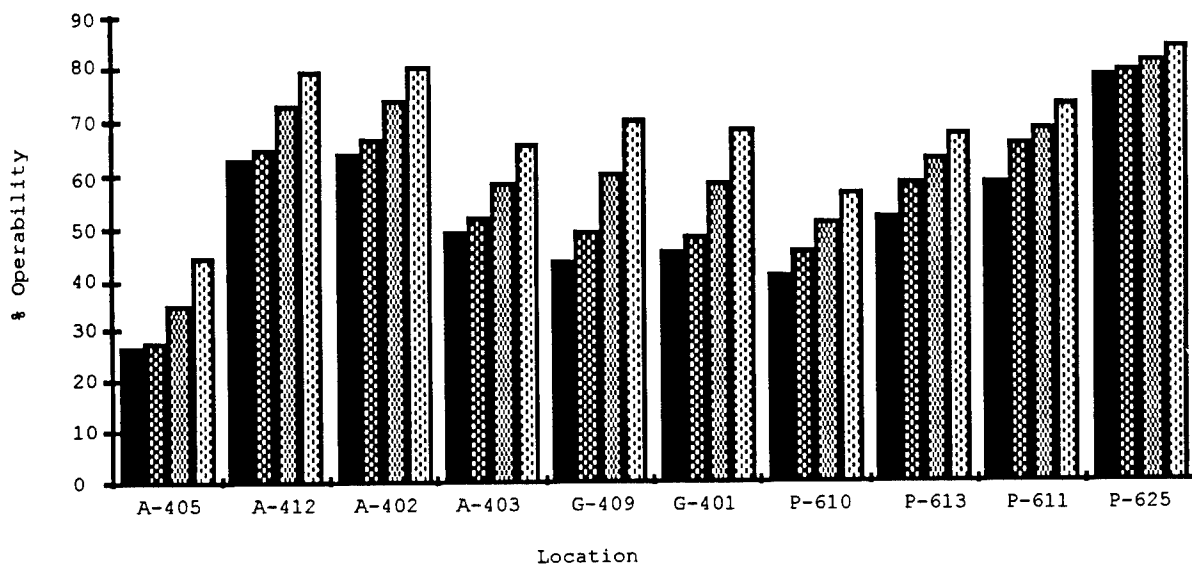


Figure 11 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Economical Speed Ops, Winter Wave Data; (File CG5F.grf)

47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, High Speed Ops, Winter Wave Data

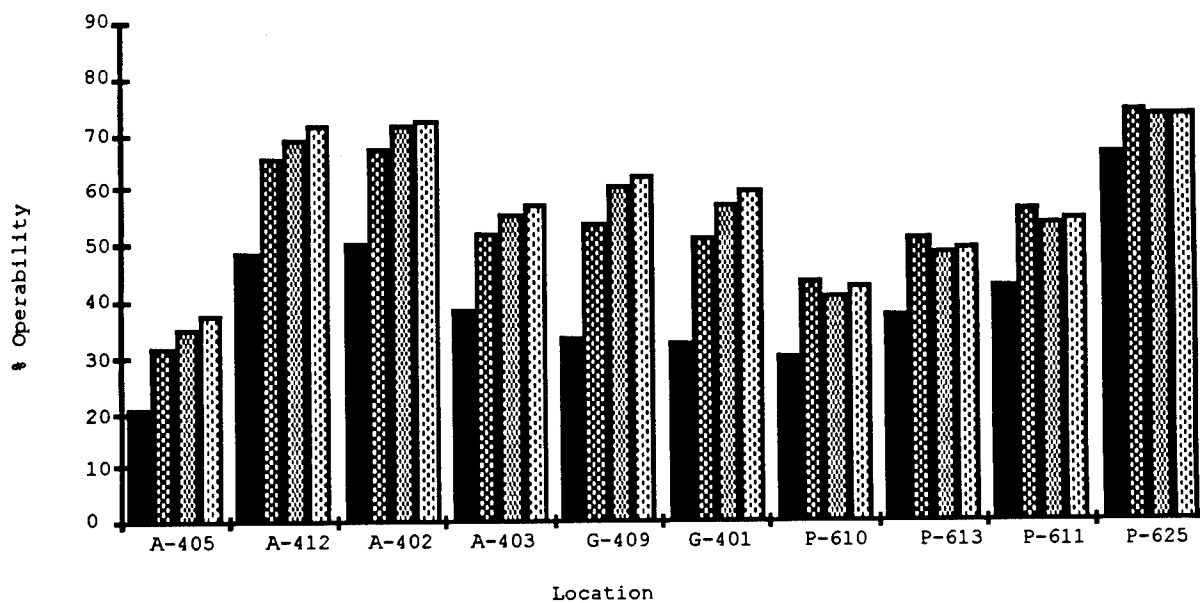


Figure 12 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, High Speed Ops, Winter Wave Data; (File CG6F.grf)

82-Ft, Base Criteria, Low Speed Ops, Winter, Spring, Summer, Fall Wave Data

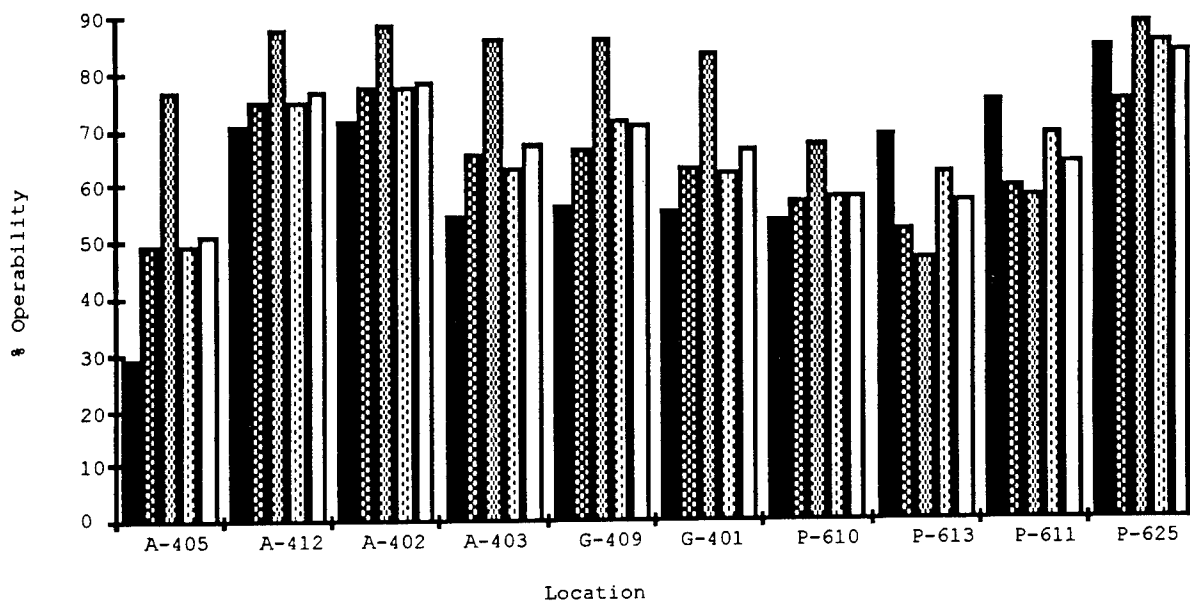


Figure 13 82-Ft, Base Criteria, Low Speed Ops, Winter, Spring, Summer, Fall, Annual Wave Data; (File CG7F.grf)

82-Ft, Base Criteria, Economical Speed Ops, Winter, Spring, Summer, Fall Wave Data

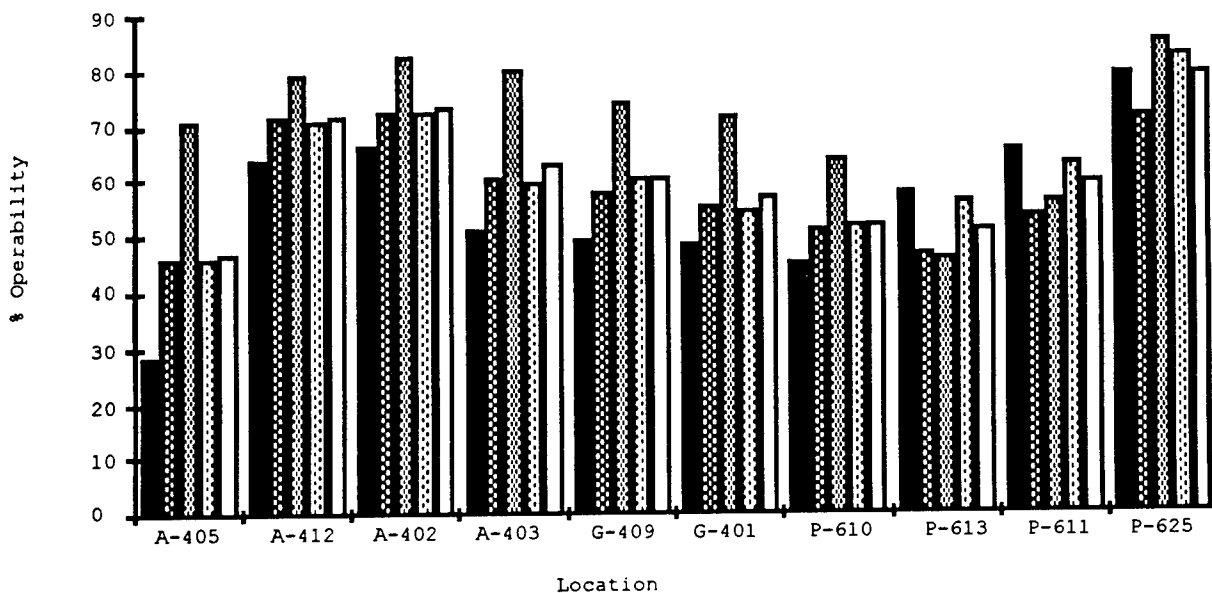


Figure 14 82-Ft, Base Criteria, Economical Speed Ops, Winter, Spring, Summer, Fall, Annual Wave Data; (File CG7F.grf)

Speed Effect at Grid Point A-405 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

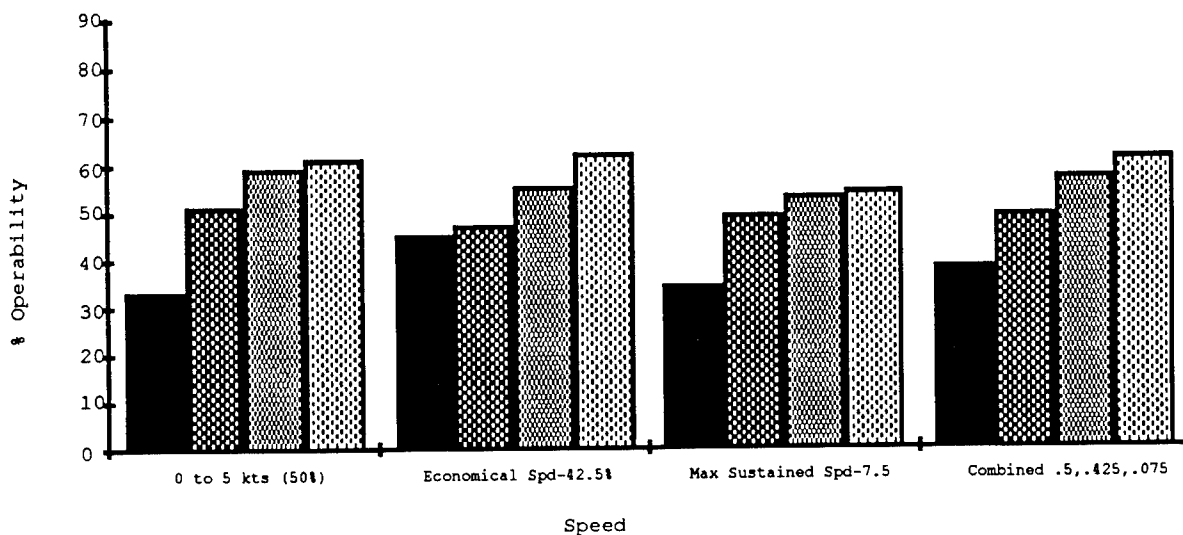


Figure 15 Speed Effect at Grid Point A-405 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave File; (File CG9F.grf)

Speed Effect at Grid Point P-610 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

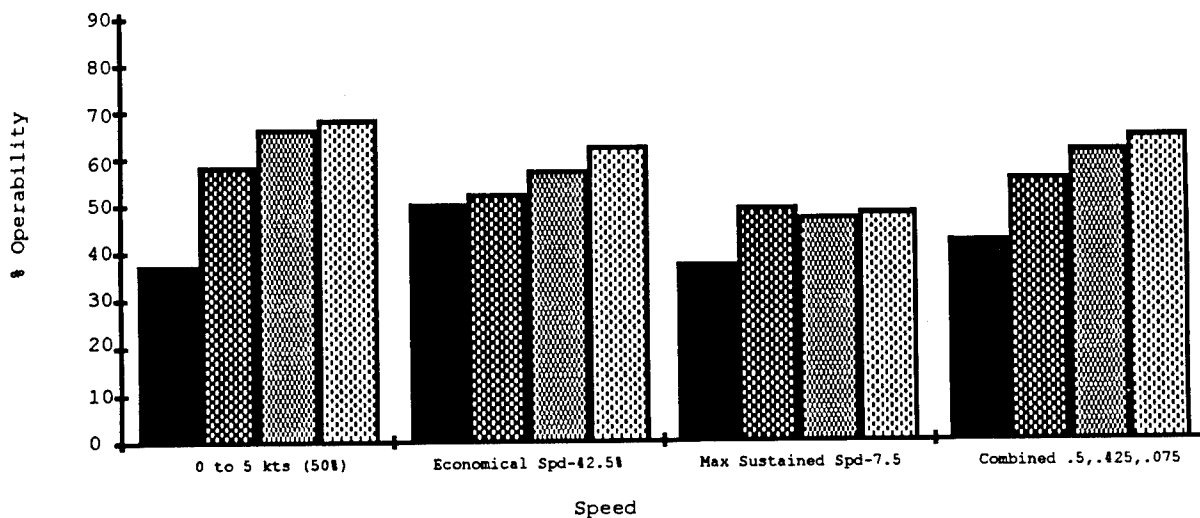


Figure 16 Speed Effect at Grid Point P-610 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG10F.grf)

Speed Effect at Grid Point P-625 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

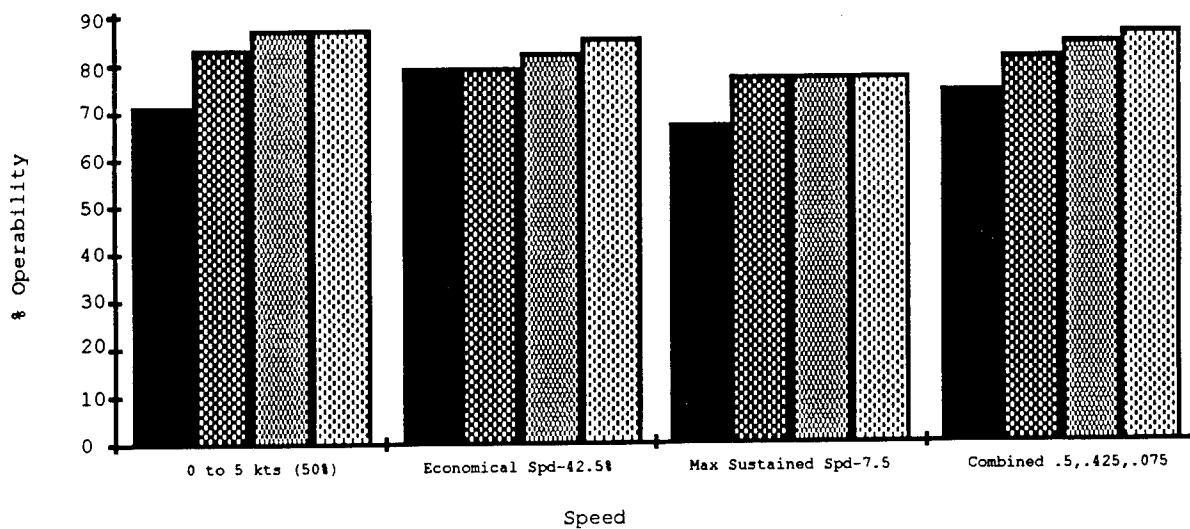


Figure 17 Speed Effect at Grid Point P-625 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG11F.grf)

Speed Effect at Grid Point A-402 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

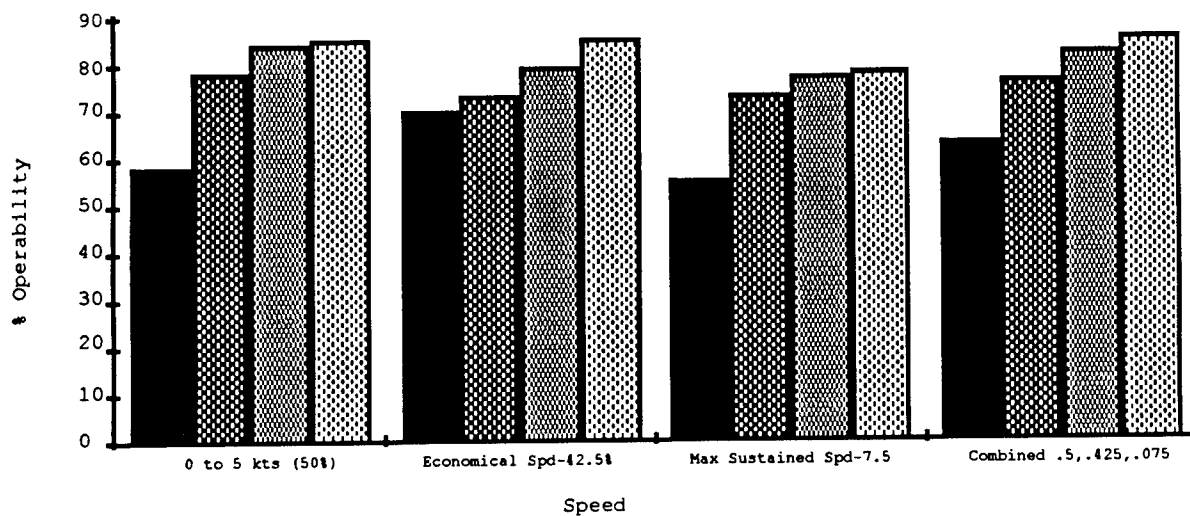


Figure 18 Speed Effect at Grid Point A-402 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG12F.grf)

Speed Effect at Grid Point G-401 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

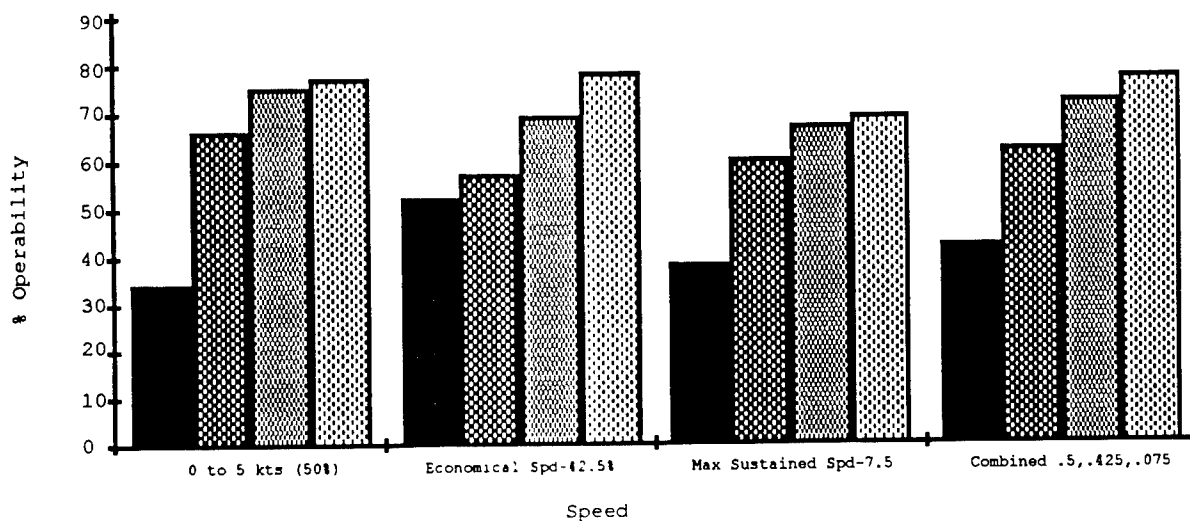


Figure 19 Speed Effect at Grid Point G-401 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG13F.grf)

Speed Effect at Grid Point G-409 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

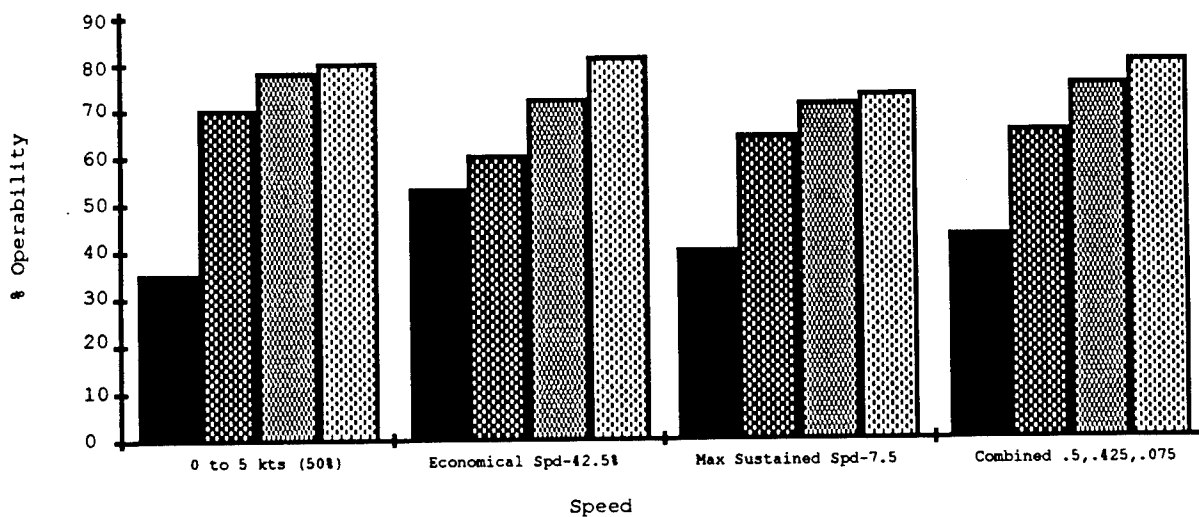


Figure 20 Speed Effect at Grid Point G-409 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG14F.grf)

Speed Effect at Grid Point A-403 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

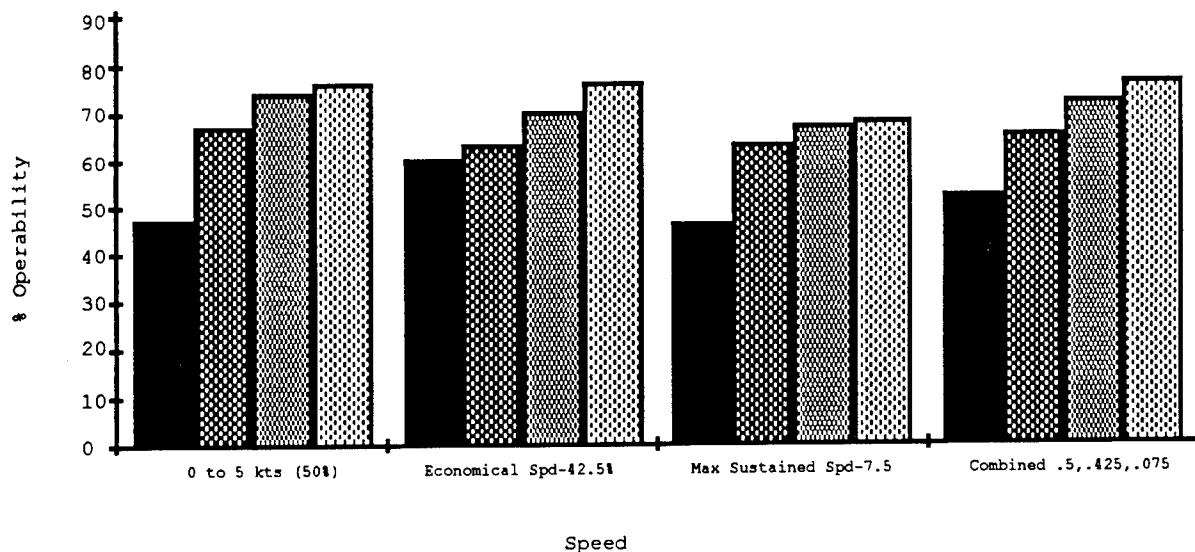


Figure 21 Speed Effect at Grid Point A-403 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG15F.grf)

Speed Effect at Grid Point A-412 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

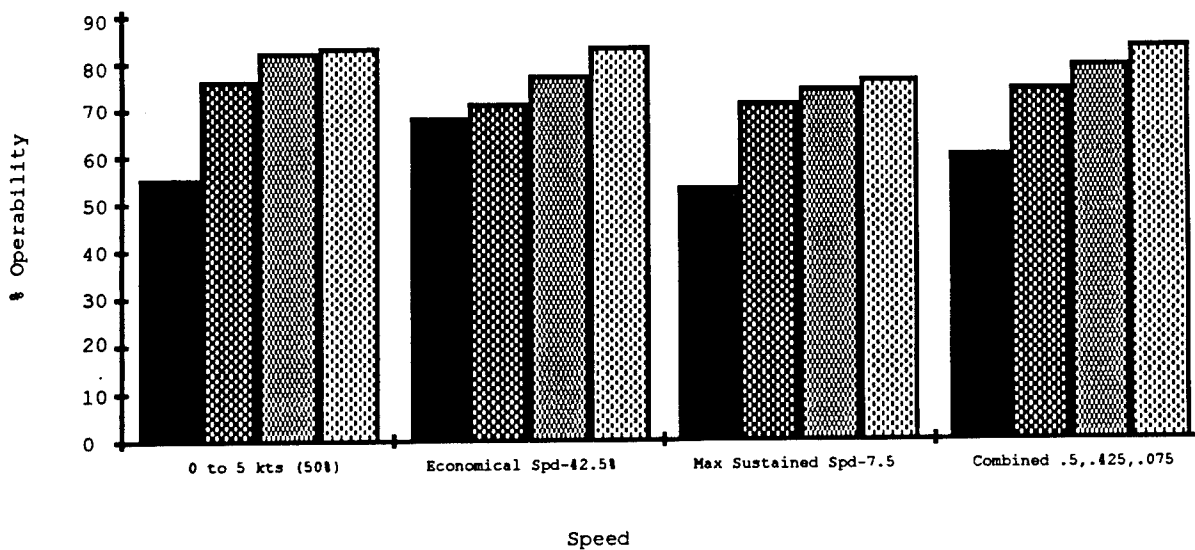


Figure 22 Speed Effect at Grid Point A-412 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG16F.grf)

Speed Effect at Grid Point P-611 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

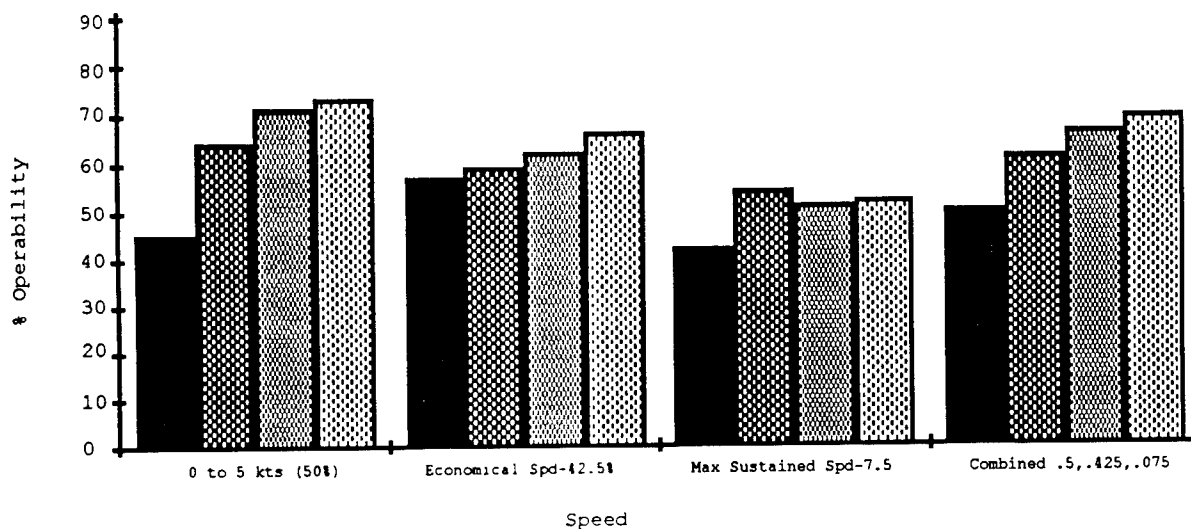


Figure 23 Speed Effect at Grid Point P-611 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG17F.grf)

Speed Effect at Grid Point P-613 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data

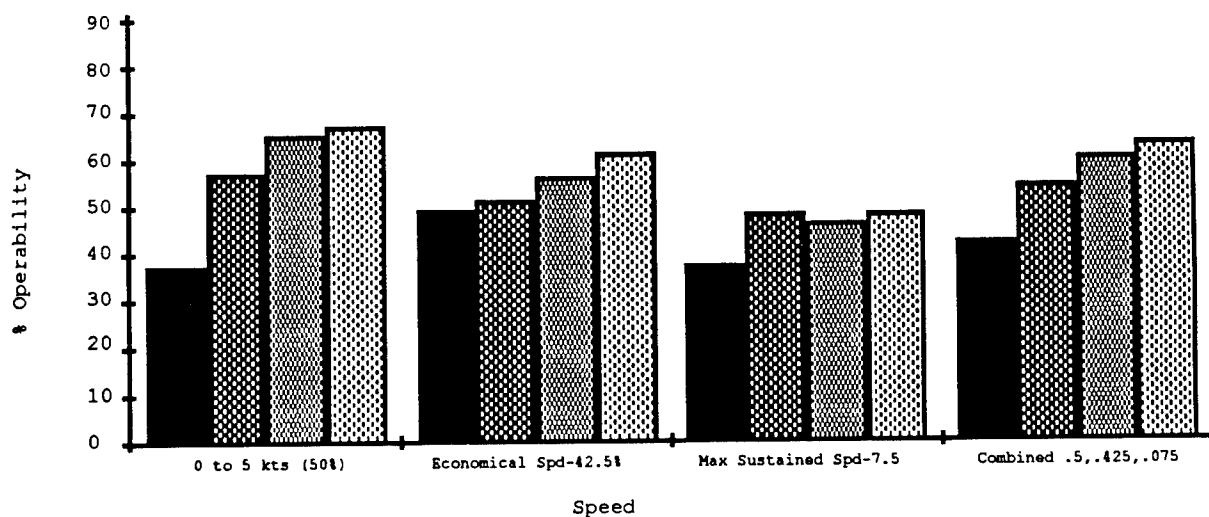


Figure 24 Speed Effect at Grid Point P-613 for USCGC 47-Ft, 82-Ft, 110-Ft Unstab & 110-Ft Stab; Base Criteria Set, Annual Wave Data; (File CG18F.grf)

Boat Effect at Grid Point P-613 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%), Base Criteria Set, Annual Wave Data

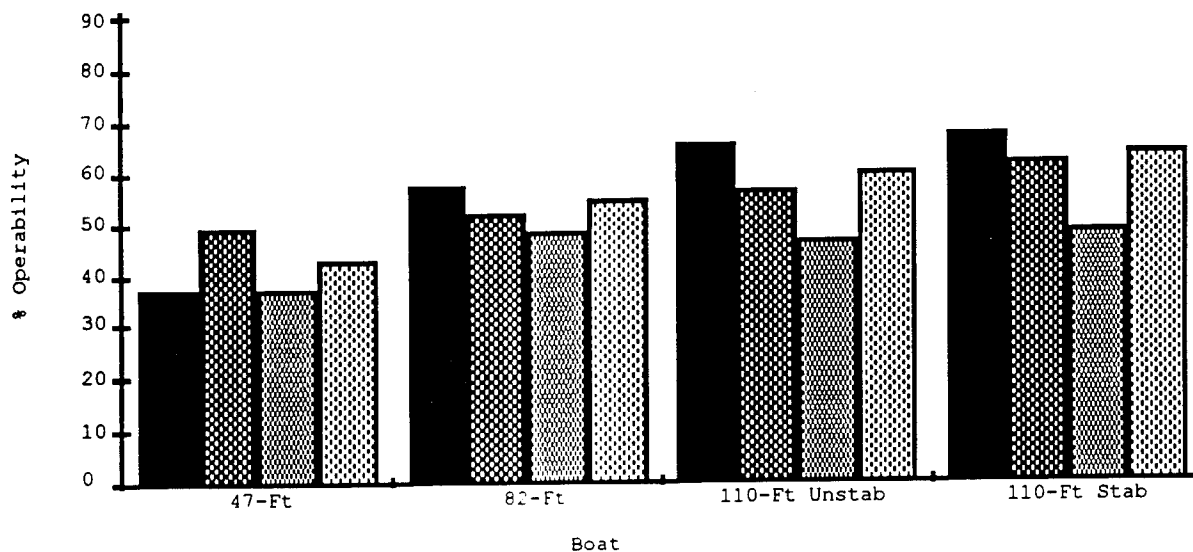


Figure 25 Boat Effect at Grid Point P-613 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%) Base Criteria Set, Annual Wave Data; (File CG19F.grf)

Boat Effect at Grid Point A-405 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%), Combined (.5+, .425+, .075), Base Criteria Set, Annual Wave Data

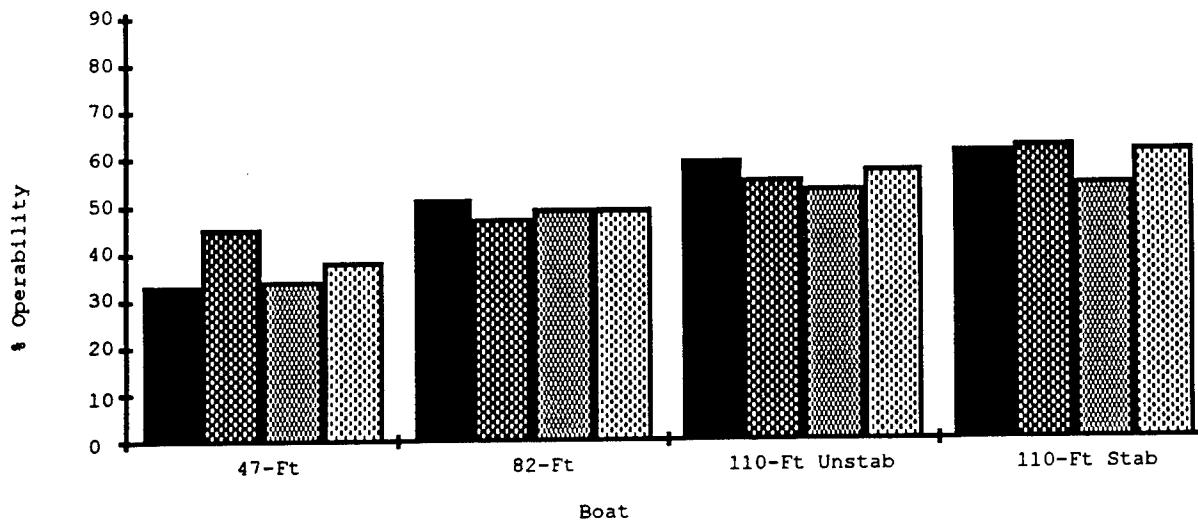


Figure 26 Boat Effect at Grid Point A-405 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%) Base Criteria Set, Annual Wave Data; (File CG20F.grf)

Boat Effect at Grid Point G-401 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%), Combined (.5+, .425+, .075), Base Criteria Set, Annual Wave Data

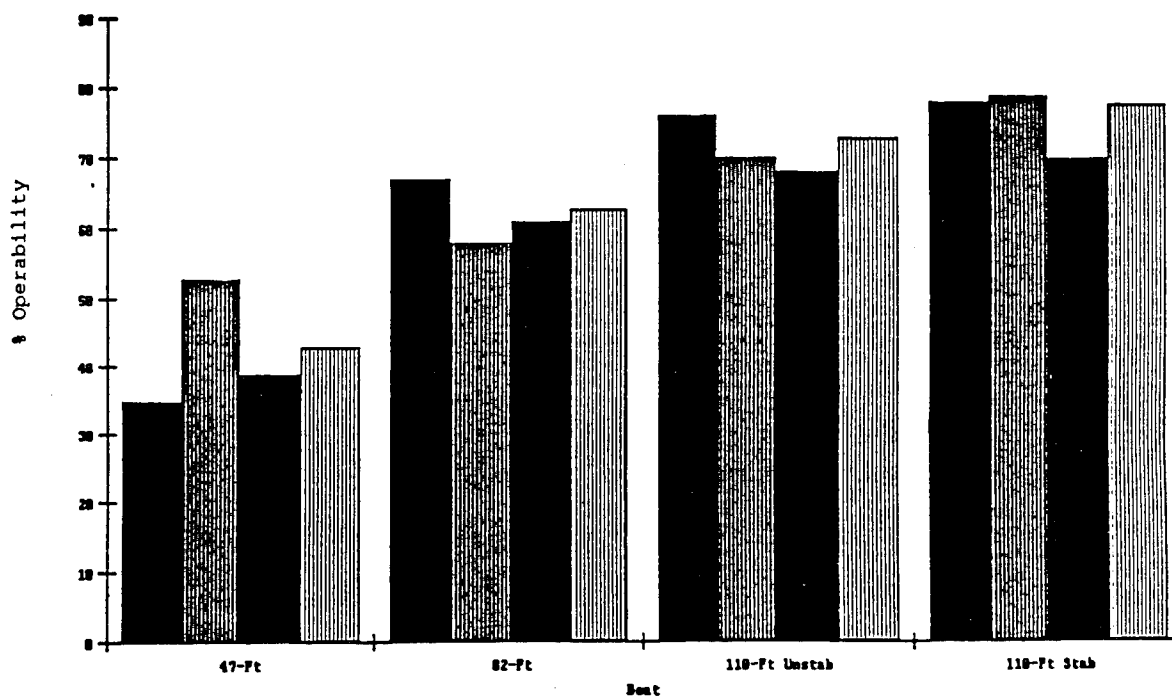


Figure 27 Boat Effect at Grid Point G-401 for Low Speed (50%), Economical Speed (42.5%), Max Sustained Speed (7.5%) Base Criteria Set, Annual Wave Data; (File CG21F.grf)

Table 1 Point Locations for 1993 USCG Seakeeping Criteria Boat Series

POINT LOCATIONS (as given by: station number, distance off centerline
(positive to port), distance above the baseline)

ABSOLUTE MOTIONS

Point Location	CG 110			CG 82		CG 47	
	Pilot House forward of chart table (8.65, 2', -26')	Pilot House at Helmsman Chair (8.21, 0', 20')	Closed Bridge, Helmsman Chair (8.75, -1.5', 10')	Forward Berthing, Port/Top Bunk (3.08, 5', 12')	Forward Berthing, Port/Top Bunk (3.33, 5', 12')	Survivor's Chamber, Port Bench (13.98, 2.5', 6')	Open Bridge, Helmsman Chair (11.18, -2.5', 14.5')
Point Location 1							
Point Location 2							
Point Location 3							

RELATIVE MOTIONS

Point Location 1	Port Propeller Tip, Emergence (19.08, 3.75', 3.71')	Port Propeller Tip, Emergence (18.90, 4.16', 3.75')	Port Propeller Tip, Emergence (18.40, 2.97', 0.57')
Point Location 2	Station 2, Bottom Slamming (2, 0', 1.7')	Station 2, Bottom Slamming (2, 0', 2')	Station 2, Bottom Slamming (2, 0', 0.66')
Point Location 3	Main Deck, Aft of Boat Davit, Stbd Rail, Wetness (15.96, -8.5', 13')	Main Deck Boat Deck, Stbd Rail, Wetness (15.38, -7.5', 10.5')	Open Bridge, Helmsman Chair, Wetness (11.18, -2.5', 14.5')

Table 2 Ship Particulars for 1993 USCG Seakeeping Criteria Boat Series

SHIP PARTICULARS

	<u>SMP Data</u>			<u>Data From Stability Tests</u>		
	<u>CG 110</u>	<u>CG 82</u>	<u>CG 47</u>	<u>CG 110</u>	<u>CG 82</u>	<u>CG 47</u>
CLASS	C	C	A	C	C	-
DRAFT (Feet)	7.0	5.95	2.67	7.0	5.95	2.67
BEAM (Feet)	19.26	15.78	12.78	19.26	15.78	12.78
LPP (Feet)	104.0417	78.0	42.917	104.0417	78.0	42.917
DISPL (SWLT)	151.5	71.5	18.2	152.48	72.3	18.99
KG (Feet)	7.86	7.21	5.35	8.57	8.55	5.17
GM (Uncorrected) (Feet)	4.88	3.24	4.24	4.88	3.24	4.24
KM (Feet)	12.74	10.45	9.59	13.45	11.79	9.41
ROLL PERIOD (Seconds)	4.11	4.19	3.07	4.17	4.19	2.97
ROLL GYRADIUS	.37B	.37B	.37B	-	-	-

FULL LOAD CONDITIONS

Table 3 Computer Programs for Prediction of '93 USCG Boat Series

- 1) SMP-93 For Ship Motion Origin Transfer Function Files
- 2) SEP-93 For Percent Time of Operability Predictions
- 3) MSI-93 For Calculation of Required MSI as Data Base Input to SEP
- 4) SLIDETIP-93 For calculation of the required MII Data Base Input to SEP
- 5) WINDSB. For Creation of Wind-Wave Height-Wave Period Data Base required for 1993 USCG Boat Series SEP input. 10 Block MICROVAX2 1-12-93 11:16:36 AM
- 6) HTDP-93 For Creation of Wave Height-Wave Period Data Base required for 1993 USCG Boat Series SEP input. 11 Blocks MICROVAX2 6-11-93 14:14:45 PM
- 7) SMPMSI-93 For calculation of 1/3 Octave Band Based MSI used for comparison with Standard 1980 MSI calculation procedure.
- 8) STH-93 For Boat Motion Time History for 60 Deg Bow Sea at 5 knots - MSI Validation
- 9) COLJAN93 For STH-93 Time History Evaluation of 82-Ft Cutter - Roll/Vertical Acceleration DLPLOT.EXE 230,966 bytes 3-11-93 9:04:46 AM
- 10) AOGP-91.EXE For Boat Motion Polar Plots of Roll & Vertical Accelerations at Speeds in 2 knot Increments from 0 - 10 kts AOGP-91.EXE 321,339 bytes 8-15-91 3:06:18 PM
- 11) SEPANL.EXE For Extraction of PTO and WPTO and Calculation of Percentage of Occurrence of Various Limiting Criteria

Table 4 WPTO Weighting Factors for 110-Ft cutter at Economical Speed of 10 kts

		SHIP HEADING ANGLE IN DEGREES (180 = HEAD SEAS)																							
SPEED	(KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0	345	330	315	300	285	270	255	240	225	210	195
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10		2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: The same weighting factors were applied at each speed and further the weighting factors were the same for all boats.

Table 5 Definitions of Ship/Boat Heading Angles in SMP and SEP

HEADING Definitions:

SMP	Head Sea = 0 Deg, Stbd Beam = 90 Deg	Following = 180 Deg
SEP	Head Sea = 180 Deg, Port Beam = 90 Deg	Following = 0 Deg
	SMP	SEP
	Head Seas	0
	Stbd Bow Seas	15
	Stbd Bow "	30
	Stbd Bow ,	45
	Stbd Beam	60
	Stbd Beam	75
	Stbd Beam,	90
	Stbd Beam	105
	Stbd Qtr ,	135
	Stbd Qtr	150
	Stbd Following	165
	Following,	180
	Port Following	195
	Port Qtr	210
	Port Qtr ,	225
	Port Beam	240
	Port Beam	255
	Port Beam,	270
	Port Beam	285
	Port Beam	300
	Port Bow	315
	Port Bow	330
	Port Bow	345

Wave Lengths, Lambda, and Heights (1/7) of Breaking Waves & Height (1/25) of Max Significant Wave Height during rapidly building storms corresponding to the SPECTRAL MODAL PERIOD

Lambda	52.5	118	204	288	379	482	609	788	976	1136
1/7 WH	7.5	16.9	29.1	41.2	54.2	68.9	---	---	---	---
1/25 WH	2.1	4.7	8.1	11.5	15.2	19.3	24.4	31.5	39.1	46.1

Original '93 CG Series SOWN SPECTRAL MODAL PERIOD (SEC)
3.2 4.8 6.3 7.5 8.6 9.7 10.9 12.4 13.8 15.0 ...

Lambda	32.1	52.5	66.5	90.4	118	204	288	379	482	609
1/7 WH	4.6	7.5	9.5	12.9	16.9	29.1	41.2	54.2	68.9	---
1/25 WH	1.3	2.1	2.7	3.6	4.7	8.1	11.5	15.2	19.3	24.4

11 Jun Revision to '93 CG Series SEP SOWN SPECTRAL MODAL PERIOD (SEC)
2.5 3.2 3.6 4.2 4.8 6.3 7.5 8.6 9.7 10.9 ...

Revised '93 CG Series SEP SOWN SPECTRAL MODAL PERIOD (SEC)
2.5 3.2

Table 6 Ship Natural Motion Periods Based on Transfer Functions

0 Speed Beam Sea for Heave & Roll & Head Sea for Pitch

Periods, Seconds	CV64	CV41 BL	DD965	AOE1	F1052	FFG8	110	82'	47'
T-Heave sec	9.3	9.8	6.3	9.0	5.7	5.2	3.7	3.5	---
T-Roll sec	25.1	12.0	15.7	10.9	12.6	11.4	4.1	4.2	3.1
T-Pitch sec	15.7	14.0	10.9	13.2	9.7	9.7	4.8	4.5	3.3

Table 7 Speed Selection Summary for 1993 CG Boat Series

	Set #1 Speed - kts	Set #2 Speed - kts	Set #3 Speed - kts
47 ft	0, 5	8	22
83 ft	0, 5	8	18
110 ft u	0, 5	10	25
110 ft s	0, 5	10	25

Table 8

82-FT Boat Sample Extract of SEP Output at 0 and 8 knots with Base Criteria Set applied to Boat Launch Location and Pilot House, Annual Wave Data - Grid Point 401 Limiting Significant Wave Heights, Limiting Seakeeping Criteria (Factors), and Percent Time of Operation

CRITERION LABEL	SEAKEEPING MOTION CRITERIA - BOAT LAUNCH LOCATION			SEAKEEPING MOTION CRITERIA - PILOT HOUSE		
	CRITERION	STATION	Y (FT)	CRITERION	STATION	Z (FT)
R	8.0 DEGREES ROLL, SIG AMP			8.0 DEGREES ROLL, SIG AMP		
P	6.0 DEGREES PITCH, SIG AMP			6.0 DEGREES PITCH, SIG AMP		
W	20.0 WETNESSES PER HOUR	15.38	-7.5	20.0 WETNESSES PER HOUR	15.38	-7.5
S	30.0 SLAMS PER HOUR	2.00	0.0	30.0 SLAMS PER HOUR	2.00	0.0
A	0.4 G'S VERTICAL ACCELERATION, SIG AMP	15.38	-7.5	0.4 G'S VERTICAL ACCELERATION, SIG AMP	8.21	0.0
LA	0.2 G'S LATERAL ACCELERATION, SIG AMP	15.38	-7.5	0.2 G'S LATERAL ACCELERATION, SIG AMP	8.21	0.0
LFE	0.2 G'S LFE, SIGNIFICANT AMPLITUDE	15.38	-7.5	0.2 G'S LFE, SIGNIFICANT AMPLITUDE	8.21	0.0
TIP	2.1 TIPPING INCIDENTS PER MIN	15.38	-7.5	2.1 TIPPING INCIDENTS PER MIN	8.21	0.0
MSI	5.0 MSI PERCENTAGE PER 30 MINUTES	15.38	-7.5	5.0 MSI PERCENTAGE PER 30 MINUTES	8.21	0.0

SHORT CRESTED SEAS - LIMITING SIGNIFICANT WAVE HEIGHTS IN FT

		95% CONFIDENCE BAND									
		(180 = HEAD SEAS)									
SPEED (KNOT)	180	165	150	135	120	105	90	75	60	45	30
0	3.6	3.4	2.9	2.5	2.2	2.1	2.1	2.1	2.3	2.6	3.1
8	3.0	3.0	3.2	3.0	2.6	2.4	2.4	2.5	2.8	3.2	4.0
8	3.3	3.2	3.0	2.8	2.4	2.3	2.2	2.3	2.5	2.9	3.6
(KNOT)	195	210	225	240	255	270	285	300	315	330	345
0	3.4	2.9	2.5	2.2	2.1	2.1	2.1	2.2	2.5	3.1	3.5
8	3.0	3.2	3.2	2.7	2.5	2.4	2.4	2.5	2.9	3.2	3.4
8	3.2	3.0	2.9	2.5	2.3	2.2	2.2	2.2	2.4	2.7	3.1

Minimum/Average/Max LIMITING SIGNIFICANT WAVE HEIGHT = 2.1/2.9/23.0 FT

		95 PERCENT CONFIDENCE BAND									
		(180 = HEAD SEAS)									
SPEED (KNOT)	180	165	150	135	120	105	90	75	60	45	30
0	78	74	69	64	61	60	60	61	65	71	75
8	70	71	72	71	67	64	68	69	75	83	91
8	74	74	73	70	65	62	63	65	70	77	83
(KNOT)	195	210	225	240	255	270	285	300	315	330	345
0	74	70	68	61	58	57	58	61	67	71	74
8	79	80	78	68	64	62	63	65	68	71	72
8	77	75	71	65	61	60	61	63	67	71	73

MIN PERCENT TIME OF OPERATION = 62%; UNWEIGHTED AVERAGE % PTO = 71%
WEIGHTED AVERAGE PERCENT TIME OF OPERATION = 74%

SHORT CRESTED SEAS LIMITING SIGNIFICANT WAVE HEIGHTS IN FT

		95% CONFIDENCE BAND									
		(180 = HEAD SEAS)									
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30
0	2.4	2.3	2.0	1.5	1.3	1.3	1.3	1.3	1.4	1.8	2.2
8	2.1	2.1	2.1	2.0	1.8	1.5	1.5	1.7	2.0	2.2	2.9
8	2.2	2.2	2.0	1.7	1.5	1.4	1.4	1.5	1.7	2.0	2.6
(KNOTS)	195	210	225	240	255	270	285	300	315	330	345
0	2.6	2.2	1.8	1.4	1.3	1.3	1.3	1.3	1.5	2.0	2.3
8	3.0	2.8	2.2	2.0	1.7	1.5	1.5	1.6	2.0	2.1	2.1
8	2.8	2.5	2.0	1.7	1.5	1.4	1.4	1.5	1.7	2.0	2.2

Minimum/Average/Max LIMITING SIGNIFICANT WAVE HEIGHT = 1.3/2.1/23.0 FT

LIMITING SEAKEEPING FACTORS												95 PERCENT CONFIDENCE BAND														
SHIP HEADING ANGLE (DEG)												(180 = HEAD SEAS)														
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0	15	30	45	60	75	90	105	120	135	150	165	180	
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	
8	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	
SPEED (KNOTS)	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570
0	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	
8	S	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0	15	30	45	60	75	90	105	120	135	150	165	180	
0	72	69	60	52	46	43	43	45	50	57	68	75	78	81	84	87	90	93	96	99	102	105	108	111	114	
8	56	56	55	52	48	47	48	53	62	73	87	98	99	100	101	102	103	104	105	106	107	108	109	110	111	
8	64	62	58	52	47	45	45	49	56	65	78	85	89	92	95	98	101	104	107	110	113	116	119	122	125	
SPEED (KNOTS)	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480	495	510	525	540	555	570
0	74	68	57	50	45	43	43	46	52	60	69	78	81	84	87	90	93	96	99	102	105	108	111	114	117	
8	76	71	62	56	52	48	47	48	52	58	65	73	78	81	84	87	90	93	96	99	102	105	108	111	114	
8	75	69	60	53	48	45	45	47	52	58	65	73	78	81	84	87	90	93	96	99	102	105	108	111	114	

MINUNWEIGHTED AVERAGE PERCENT TIME OF OPERATION = 47/59%
WEIGHTED AVERAGE PERCENT TIME OF OPERATION = 62%

82-FT Boat Sample Extract of SEP Output at 0 and 10 knots with Base Criteria Set applied to Boat Launch Location and Pilot House, Annual Wave Data - Grid Point 401 Limiting Significant Wave Heights, Limiting Seakeeping Criteria (Factors), and Percent Time of Operation

SEAKEEPING MOTION CRITERIA - BOAT LAUNCH LOCATION										SEAKEEPING MOTION CRITERIA - PILOT HOUSE									
CRITERION LABEL	CRITERION					STATION	Y (FT)	Z (FT)		CRITERION LABEL	CRITERION					STATION	Y (FT)	Z (FT)	
R	8.0	DEGREES ROLL, SIG AMP				15.38	-7.5	4.55		R	8.0	DEGREES ROLL, SIG AMP			15.38	-7.5	4.55		
P	6.0	DEGREES PITCH, SIG AMP				2.00	0.0	-3.95		P	6.0	DEGREES PITCH, SIG AMP			2.00	0.0	-3.95		
W	20.0	WETNESSES PER HOUR				15.38	-7.5	4.55		W	20.0	WETNESSES PER HOUR			8.21	0.0	14.05		
S	30.0	SLAMS PER HOUR				15.38	-7.5	4.55		S	30.0	SLAMS PER HOUR			8.21	0.0	14.05		
A	0.4	G'S VERTICAL ACCELERATION, SIG AMP				15.38	-7.5	4.55		A	0.4	G'S VERTICAL ACCELERATION, SIG AMP			8.21	0.0	14.05		
LA	0.2	G'S LATERAL ACCELERATION, SIG AMP				15.38	-7.5	4.55		LA	0.2	G'S LATERAL ACCELERATION, SIG AMP			8.21	0.0	14.05		
LFE	0.2	G'S LIFE, SIGNIFICANT AMPLITUDE				15.38	-7.5	4.55		LFE	0.2	G'S LIFE, SIGNIFICANT AMPLITUDE			8.21	0.0	14.05		
TIP	2.1	TIPPING INCIDENTS PER MIN				15.38	-7.5	4.55		TIP	2.1	TIPPING INCIDENTS PER MIN			8.21	0.0	14.05		
MSI	5.0	MSI PERCENTAGE PER 30 MINUTES				15.38	-7.5	4.55		MSI	5.0	MSI PERCENTAGE PER 30 MINUTES			8.21	0.0	14.05		
SHORT CRESTED SEAS - LIMITING SIGNIFICANT WAVE HEIGHTS IN FT										SHORT CRESTED SEAS - LIMITING SIGNIFICANT WAVE HEIGHTS IN FT									
95% CONFIDENCE BAND										95% CONFIDENCE BAND									
SHIP HEADING ANGLE (DEG)										SHIP HEADING ANGLE (DEG)									
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0						
0	3.8	3.4	2.9	2.5	2.2	2.1	2.1	2.1	2.3	2.6	3.1	3.6	3.9						
18	2.5	2.5	2.6	2.7	3.0	3.2	3.5	4.1	4.9	6.0	7.1	6.9	6.8						
3.0	2.9	2.7	2.6	2.6	2.8	3.1	3.6	4.3	5.1	5.3	5.3	5.3							
(KNOTS)	195	210	225	240	255	270	285	300	315	330	345								
0	3.4	2.9	2.5	2.2	2.1	2.1	2.1	2.1	2.2	2.5	3.1	3.5							
18	2.5	2.7	2.9	3.2	3.7	3.3	3.1	3.0	2.9	2.7	2.6								
3.0	2.6	2.7	2.7	2.9	2.7	2.6	2.6	2.7	2.9	3.1									
Minimum/Average/Max LIMITING SIGNIFICANT WAVE HEIGHT = 2.1/3.2/3.0 FT										Minimum/Average/Max LIMITING SIGNIFICANT WAVE HEIGHT = 1.2/2.3/2.0 FT									
LIMITING SEAKEEPING FACTORS										LIMITING SEAKEEPING FACTORS									
SHIP HEADING ANGLE (DEG)										SHIP HEADING ANGLE (DEG)									
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0						
0	R	R	R	R	R	R	R	R	R	R	R	R	R						
18	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	R	S	S	S						
(KNOTS)	195	210	225	240	255	270	285	300	315	330	345								
0	R	R	R	R	R	R	R	TIP	TIP	TIP	TIP	TIP	TIP						
18	S	S	S	S	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP						
SHIP HEADING ANGLE (DEG)										SHIP HEADING ANGLE (DEG)									
SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0						
0	78	74	69	64	61	60	61	65	71	75	78	78	78						
18	61	62	64	67	70	72	75	80	93	97	99	99	99						
69	70	69	68	67	66	67	71	79	84	87	89	89							
(KNOTS)	195	210	225	240	255	270	285	300	315	330	345								
0	74	70	66	61	58	57	58	61	67	71	74								
18	65	68	73	75	74	72	70	68	68	64	62								
89	69	69	70	68	66	65	64	65	66	66	68								

MIN PERCENT TIME OF OPERATION = 61%; UNWEIGHTED AVERAGE % PTO = 71%
WEIGHTED AVERAGE PERCENT TIME OF OPERATION = 75%

MIN/PERCENT TIME OF OPERATION = 34%; UNWEIGHTED
WEIGHTED AVERAGE PERCENT TIME OF OPERATION = 61%

82-FT Boat Sample Extract of SEP Output at 0 knots with Base Criteria Set applied to Boat Launch Location and Pilot House, Annual Wave Data - Grid Point 401 Limiting Significant Wave Heights Due to Ship Motions and Corresponding Limiting Seakeeping Criteria (Failing Criteria)

Due to Ship Motions and Corresponding Limiting Seakeeping Criteria		Due to Ship Motions and Corresponding Limiting Seakeeping Criteria	
LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Low Speed Run, Boat Launching Station, Original SOWN Wave Data Base		LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Economical Speed Run, Pilot House, Original SOWN Wave Data Base	
Wave Period Distribution	Wave Period Distribution	Wave Period Distribution	Wave Period Distribution
SPEED	HEADING	SPEED	HEADING
PERIOD DISTRIBUTION	PERIOD DISTRIBUTION	PERIOD DISTRIBUTION	PERIOD DISTRIBUTION
15	15	15	15

[illegible]

Table 11 82-FT Boat Sample Extract of SEP Output at 8 knots with Base Criteria Set applied to Boat Launch Location and Pilot House, Annual Wave Data - Grid Point 401 Limiting Significant Wave Heights Due to Ship Motions and Corresponding Limiting Seakeeping Criteria (Failing Criteria)

LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Economical Speed Run, Boat Launching Station, Original SOWN Wave Data											
Base Wave Period Distribution											
SPEED (KTS)	HEADING (DEG)	SPECTRAL MODAL PERIOD (SEC)									
		3.2	4.8	6.3	7.5	8.6	9.7	10.9	12.4		
8	180	3.7	3.0	3.8	4.1	4.1	4.2	4.4	4.6	4.8	15.0
8	165	3.7	3.0	3.8	4.1	4.2	4.3	4.4	4.6	4.9	15.1
8	150	3.8	3.2	4.0	4.2	4.2	4.3	4.5	4.8	13.5	15.2
8	135	3.8	3.0	3.8	4.2	4.3	4.4	4.6	4.9	11.9	13.9
8	120	3.1	2.6	3.3	4.0	4.4	4.5	4.7	5.0	10.9	12.7
8	105	2.7	2.4	3.1	3.8	4.4	4.6	4.9	5.7	10.5	12.2
8	90	2.5	2.4	3.0	3.8	4.5	4.7	5.0	5.8	10.6	12.4
8	75	2.5	2.5	3.2	4.0	4.7	5.1	5.4	6.1	11.3	13.2
8	60	2.8	2.8	3.6	4.5	5.6	6.8	8.4	10.5	12.7	14.8
8	45	3.3	3.2	4.2	5.4	6.7	8.2	10.0	12.5	15.2	17.6
8	30	4.1	4.0	5.4	6.9	8.6	10.4	12.7	15.9	19.2	22.2
8	15	5.5	5.5	7.4	9.3	11.5	13.3	15.2	17.8	20.4	22.8
8	0	6.2	6.8	8.9	10.4	11.6	13.0	14.9	17.5	20.0	22.3
8	345	4.9	3.4	4.0	4.0	4.1	4.2	4.3	4.5	4.7	5.0
8	330	4.1	3.2	3.6	4.0	4.1	4.2	4.3	4.5	4.7	4.9
8	315	3.4	2.9	3.3	3.9	4.1	4.1	4.3	4.4	4.7	4.9
8	300	3.0	2.5	3.2	3.8	4.1	4.2	4.3	4.5	4.7	5.0
8	285	2.6	2.4	3.1	3.9	4.1	4.2	4.3	4.5	4.8	13.2
8	270	2.4	2.4	3.0	3.8	4.1	4.2	4.4	4.6	5.0	12.4
8	255	2.5	2.5	3.1	3.8	4.2	4.3	4.5	4.9	10.5	12.2
8	240	2.7	2.9	3.3	4.0	4.3	4.5	4.8	5.2	10.9	12.7
8	225	3.2	3.4	3.7	4.3	4.5	4.8	5.2	5.7	11.9	13.9
8	210	3.8	3.2	4.1	4.7	5.1	5.6	6.1	6.7	13.5	15.8
8	195	3.7	3.0	3.8	4.9	6.2	7.7	9.5	12.1	14.9	17.6
8	180	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	165	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	150	S	S	TIP	MSI	MSI	MSI	MSI	MSI	R	MSI
8	135	TIP	TIP	TIP	R	R	R	R	R	R	R
8	120	TIP	TIP	R	R	R	R	R	R	R	R
8	105	TIP	TIP	R	R	R	R	R	R	R	R
8	90	TIP	R	R	R	R	R	R	R	R	R
8	75	TIP	R	R	R	R	R	R	R	R	R
8	60	TIP	R	R	R	R	R	R	R	R	R
8	45	TIP	R	R	R	R	R	R	R	R	R
8	30	R	R	R	R	R	R	R	R	R	R
8	15	R	R	R	R	R	R	R	R	R	R
8	0	S	S	R	P	P	P	P	P	P	P
8	345	MSI	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	330	R	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	315	R	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	300	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	285	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	270	TIP	TIP	R	R	MSI	MSI	MSI	MSI	MSI	MSI
8	255	TIP	TIP	R	R	MSI	MSI	MSI	MSI	MSI	MSI
8	240	TIP	R	R	R	MSI	MSI	MSI	MSI	MSI	MSI
8	225	TIP	R	R	R	MSI	MSI	MSI	MSI	MSI	MSI
8	210	S	S	R	MSI	MSI	MSI	MSI	MSI	MSI	MSI
8	195	S	S	S	S	S	S	S	S	S	S
LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Economical Speed Run, Pilot House, Original SOWN Wave Data											
Base Wave Period Distribution											
SPEED (KTS)	HEADING (DEG)	SPECTRAL MODAL PERIOD (SEC)									
		3.2	4.8	6.3	7.5	8.6	9.7	10.9	12.4		
8	180	3.0	2.1	2.4	3.2	4.1	4.2	4.3	4.5	4.7	4.9
8	165	3.0	2.1	2.4	3.2	4.1	4.2	4.3	4.5	4.7	4.9
8	150	2.7	2.1	2.4	3.1	4.0	4.2	4.3	4.5	4.8	5.0
8	135	2.3	2.0	2.3	3.0	3.7	4.2	4.4	4.6	4.8	10.6
8	120	2.1	1.6	2.2	2.8	3.5	4.3	4.5	4.7	8.7	10.2
8	105	1.9	1.5	2.2	2.8	3.5	4.4	4.6	4.9	8.6	10.2
8	90	1.7	1.5	2.2	2.9	3.6	4.5	4.8	5.3	9.0	10.6
8	75	1.7	1.7	2.3	3.2	4.1	4.7	5.3	6.1	10.0	11.7
8	60	2.0	2.0	2.7	3.7	4.7	5.9	7.5	9.5	11.7	13.8
8	45	2.2	2.4	3.4	4.6	6.0	7.4	9.5	12.0	14.8	17.4
8	30	2.9	3.3	4.7	6.4	8.2	10.3	12.7	15.9	19.2	22.2
8	15	4.2	5.0	6.8	9.3	11.5	13.3	15.2	17.8	20.4	22.8
8	0	5.7	6.8	9.4	11.6	13.0	14.9	17.5	20.0	22.3	25.3
8	345	3.0	2.1	2.4	3.2	4.1	4.2	4.3	4.5	4.7	4.9
8	330	2.7	2.1	2.4	3.1	4.0	4.2	4.3	4.5	4.8	5.0
8	315	2.3	2.0	2.3	3.0	3.7	4.2	4.4	4.6	4.8	10.6
8	300	2.1	1.6	2.2	2.8	3.5	4.3	4.5	4.7	8.7	10.2
8	285	1.9	1.5	2.2	2.8	3.5	4.4	4.6	4.9	8.6	10.2
8	270	1.7	1.5	2.2	2.9	3.6	4.5	4.8	5.3	9.0	10.6
8	255	1.7	1.7	2.3	3.0	3.8	4.7	5.9	7.5	9.3	10.9
8	240	2.0	2.0	2.5	3.1	3.9	4.8	6.0	7.6	9.4	11.1
8	225	2.2	2.3	2.7	3.4	4.2	5.2	6.4	8.2	10.1	11.8
8	210	2.9	2.8	3.1	3.8	4.7	5.8	7.1	9.1	11.2	13.1
8	195	3.7	3.0	3.6	4.3	5.3	6.5	8.0	10.1	12.4	14.6
SPEED HEADING											
8	180	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI
8	165	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	150	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	135	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	120	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	105	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	90	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	75	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	60	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	45	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	30	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	15	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	0	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	TIP	TIP
8	345	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	330	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	315	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	300	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	285	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	270	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	255	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	240	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	225	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	210	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI
8	195	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI

Table 12 82-FT Boat Sample Extract of SEP Output at 18 knots with Base Criteria Set applied to Boat Launch Location and Pilot House, Annual Wave Data - Grid Point 401 Limiting Significant Wave Heights Due to Ship Motions and Corresponding Limiting Seakeeping Criteria (Failing Criteria)

LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Cruising Speed Run, Boat Launching Station, Original SOWN Wave Data Base													LIMITING SIGNIFICANT WAVE HEIGHTS (FT) DUE TO SHIP MOTIONS AND CORRESPONDING FAILING CRITERIA for Cruising Speed Run, Pilot House, Original SOWN Wave Data Base												
Wave Period Distribution			SPECTRAL MODAL PERIOD (SEC)										Wave Period Distribution			SPECTRAL MODAL PERIOD (SEC)									
SPEED (KTS)	HEADING (DEG)	3.2	4.8	6.3	7.5	8.6	9.7	10.9	12.4	13.8	15.0	SPEED (KTS)	HEADING (DEG)	3.2	4.8	6.3	7.5	8.6	9.7	10.9	12.4	13.8	15.0		
18	180	4.3	2.5	2.7	3.4	3.8	4.0	4.1	4.2	4.3	4.4	18	180	3.1	1.2	1.3	1.9	2.3	2.9	3.5	4.2	4.3	4.4		
18	165	4.2	2.5	2.8	3.4	4.0	4.1	4.1	4.3	4.4	4.5	18	165	3.1	1.3	1.4	2.0	2.3	3.0	3.6	4.2	4.3	4.4		
18	150	4.2	2.6	3.0	3.6	4.0	4.1	4.2	4.3	4.4	4.5	18	150	2.9	1.3	1.5	2.1	2.5	3.2	4.0	4.2	4.3	4.4		
18	135	4.2	2.7	3.2	4.0	4.1	4.2	4.3	4.4	4.5	4.7	18	135	2.8	1.4	1.7	2.2	2.8	3.4	4.2	4.3	4.4	4.5		
18	120	4.0	3.0	3.4	4.1	4.2	4.2	4.4	4.5	4.7	4.9	18	120	2.5	1.6	2.1	2.5	3.2	4.0	4.2	4.4	4.5	4.7		
18	105	4.0	3.2	3.9	4.2	4.3	4.4	4.5	4.7	5.0	15.1	18	105	2.5	2.0	2.3	3.1	3.8	4.2	4.3	4.5	4.7	4.9		
18	90	4.1	3.5	4.3	4.3	4.4	4.6	4.8	11.5	13.8	15.4	18	90	2.6	2.2	2.8	3.6	4.2	4.3	4.5	4.8	10.6	12.4		
18	75	4.4	4.1	4.5	4.6	4.7	5.0	10.2	12.5	15.0	15.9	18	75	3.0	2.7	3.4	4.3	4.4	4.8	5.0	10.6	13.0	15.1		
18	60	5.2	4.9	5.8	6.9	8.3	9.8	11.8	14.5	17.4	20.0	18	60	3.4	3.3	4.3	4.7	4.9	8.6	10.8	13.5	16.0	17.3		
18	45	5.6	6.0	7.0	8.5	10.2	12.2	14.8	18.0	21.5	24.7	18	45	4.4	4.4	5.9	7.5	9.5	11.7	14.6	18.0	21.5	24.7		
18	30	5.7	7.1	9.4	11.5	13.6	15.1	17.2	20.1	23.1	25.8	18	30	5.7	6.6	9.0	11.5	13.6	15.1	17.2	20.1	23.1	25.8		
18	15	5.8	6.9	9.3	11.9	13.1	14.5	16.4	19.1	21.9	24.4	18	15	5.6	6.9	9.3	11.9	13.1	14.5	16.4	19.1	21.9	24.4		
18	0	5.8	6.8	9.1	11.6	12.8	14.3	16.1	18.8	21.5	24.0	18	0	5.6	6.8	9.1	11.6	12.9	14.3	16.1	18.8	21.5	24.0		
18	345	5.4	2.6	2.8	3.3	3.7	4.0	4.1	4.2	4.3	4.4	18	345	3.1	1.3	1.4	2.0	2.3	3.0	3.6	4.2	4.3	4.4		
18	330	4.8	2.7	3.1	3.3	3.7	4.0	4.1	4.2	4.3	4.4	18	330	2.9	1.3	1.5	2.1	2.5	3.2	4.0	4.2	4.3	4.4		
18	315	4.2	2.9	3.1	3.4	3.8	4.0	4.1	4.2	4.4	4.5	18	315	2.6	1.4	1.7	2.2	2.8	3.4	4.2	4.3	4.4	4.5		
18	300	3.8	3.0	3.2	3.5	4.0	4.1	4.2	4.3	4.4	4.6	18	300	2.5	1.6	2.1	2.5	3.2	4.0	4.2	4.4	4.5	4.7		
18	285	3.7	3.1	3.4	3.8	4.0	4.1	4.2	4.4	4.6	4.7	18	285	2.5	2.0	2.3	3.1	3.8	4.2	4.3	4.5	4.7	4.9		
18	270	3.8	3.3	3.8	4.0	4.1	4.2	4.4	4.6	4.8	15.0	18	270	2.6	2.2	2.8	3.6	4.2	4.3	4.5	4.8	10.6	12.4		
18	255	4.2	3.7	4.1	4.1	4.2	4.4	4.6	4.9	13.4	15.3	18	255	3.0	2.7	3.4	4.3	4.4	4.6	5.0	9.8	12.0	14.0		
18	240	4.2	3.2	3.8	4.3	4.5	4.7	8.9	11.3	13.7	15.8	18	240	3.4	3.2	3.6	4.3	4.9	6.3	7.7	9.7	11.9	13.9		
18	225	4.2	2.9	3.3	4.1	5.0	6.2	7.6	9.7	11.9	14.0	18	225	4.2	2.9	3.3	4.1	5.0	6.2	7.6	9.7	11.9	14.0		
18	210	4.2	2.7	3.0	3.6	4.5	5.5	6.8	8.6	10.6	12.5	18	210	4.2	2.7	3.0	3.6	4.5	5.5	6.8	8.6	10.6	12.5		
18	195	4.2	2.5	2.8	3.4	4.2	5.2	6.4	8.1	9.9	11.7	18	195	4.2	2.5	2.8	3.4	4.2	5.2	6.4	8.1	9.9	11.7		
18	180	S	TIP	S	S	S	S	MSI	MSI	MSI	MSI	18	180	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	165	S	TIP	S	S	S	S	MSI	MSI	MSI	MSI	18	165	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	150	S	TIP	S	TIP	S	TIP	MSI	MSI	MSI	MSI	18	150	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	135	S	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	18	135	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	120	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	120	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	105	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	R	R	18	105	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI		
18	90	TIP	TIP	MSI	MSI	MSI	MSI	MSI	R	R	R	18	90	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI	TIP	TIP		
18	75	TIP	TIP	MSI	MSI	MSI	MSI	MSI	R	R	R	18	75	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	TIP	TIP		
18	60	TIP	MSI	R	R	R	R	R	R	R	R	18	60	TIP	TIP	TIP	MSI	MSI	MSI	MSI	TIP	MSI	MSI		
18	45	S	R	R	R	R	R	R	R	R	R	18	45	TIP	TIP	TIP	TIP	TIP	TIP	R	R	R	R		
18	30	S	S	S	S	S	S	S	P	P	P	18	30	S	S	S	S	S	P	P	P	P	P		
18	15	S	S	S	S	S	S	S	P	P	P	18	15	S	S	S	S	S	P	P	P	P	P		
18	0	S	S	S	S	S	S	S	P	P	P	18	0	S	S	S	S	S	P	P	P	P	P		
18	345	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	345	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	330	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	330	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	315	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	315	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	300	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	300	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI		
18	285	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	285	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI	MSI		
18	270	TIP	TIP	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	18	270	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	TIP	TIP		
18	255	TIP	S	MSI	MSI	MSI	MSI	MSI	MSI	R	R	18	255	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	TIP	TIP		
18	240	S	S	S	S	S	S	S	S	R	R	18	240	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	LFE	LFE		
18	225	S	S	S	S	S	S	S	S	S	S	18	225	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	LFE	LFE		
18	210	S	S	S	S	S	S	S	S	S	S	18	210	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	LFE	LFE		
18	195	S	S	S	S	S	S	S	S	S	S	18	195	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	S	S		

Table 13 47-FT Boat Limiting Criteria at Low Speed - Open Bridge (Boat Station) and Closed Bridge (Pilot House) Annual Wave Data - Grid Point 401

CG47R.01 Limiting Criteria at Low Speed - Open Bridge/Boat Launch Station

LIMITING SEAKEEPING FACTORS 95% CONFIDENCE BAND

SHIP HANDLING ANGLE (DEG)

SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S
10	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	S
15	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
10	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
15	S	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP

47S.03 Limiting Criteria at 8 knots for Closed Bridge (Pilot House)

AEB47T.03 Limiting Criteria at the Pilot House for high speed

SHIP HANDLING ANGLE (DEG)

SPEED (KNOTS)	180	165	150	135	120	105	90	75	60	45	30	15	0
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
8	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	S
22	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
8	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
22	S	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP

Table 14 110-Ft Boat Unstabilized, Limiting Criteria at ALL Speeds - Boat Launch Station and Pilot House Annual Wave Data - Grid Point 401

LIMITING SEAKEEPING FACTORS

95% CONFIDENCE BAND

CG110R.07 Limiting Criteria for CG110R at Boat Launch Location

SPEED (KNOTS)	SHIP HEADING ANGLE (DEG)										(180 - HEAD SEAS)		
	180	165	150	35	120	105	90	75	60	45	30	15	0
0	MSI	MSI	R	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI
5	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP	TIP	R	R	S	S
10	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP	R	S	S
15	S	S	S	MSI	MSI	TIP	TIP	MSI	TIP	R	S	S	S
20	MSI	S	S	S	MSI	MSI	MSI	MSI	TIP	S	S	S	S
25	MSI	MSI	TIP	TIP	TIP	MSI	MSI	MSI	MSI	S	S	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI
5	S	MSI	R	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI
10	S	S	MSI	MSI	TIP	TIP	MSI	MSI	MSI	MSI	MSI
15	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
20	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
25	S	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI

CG110R.11 High Speed run 110R, Limiting Criteria for Pilot House

SPEED (KNOTS)	SHIP HEADING ANGLE (DEG)												
	180	165	150	135	120	105	90	75	60	45	30	15	0
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
10	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S
15	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S	S
20	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	TIP	S	S
25	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	TIP	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	LFE	LFE	LFE	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP
10	S	LFE	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
15	S	S	LFE	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP
20	S	S	S	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP
25	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP

Table 15 110-Ft Boat Stabilized, Limiting Criteria at ALL Speeds - Boat Launch Station and Pilot House Annual Wave Data - Grid Point 401

LIMITING SEAKEEPING FACTORS

95% CONFIDENCE BAND

CG110T.07 Limiting Criteria of 110T at Boat Launch Location

SPEED (KNOTS)	SHIP HEADING ANGLE (DEG)												
	180	165	150	135	120	105	90	75	60	45	30	15	0
0	MSI	MSI	R	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI
5	S	S	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP	R	S	S
10	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	S	S	S	S
15	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	S	S	S	S
20	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	S	S	S	S
25	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	S	S	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI
5	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
10	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
15	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
20	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI	MSI
25	S	S	S	S	MSI	MSI	MSI	MSI	MSI	MSI	MSI

CG110T.011 Limiting Criteria for Pilot House

SPEED (KNOTS)	SHIP HEADING ANGLE (DEG)												
	180	165	150	135	120	105	90	75	60	45	30	15	0
0	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	S
10	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	MSI	S	S	S
15	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	S	S	S
20	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	MSI	S	S	S
25	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	MSI	MSI	S	S	S

SPEED	195	210	225	240	255	270	285	300	315	330	345
0	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP	TIP
5	S	LFE	LFE	LFE	TIP	TIP	TIP	TIP	TIP	TIP	TIP
10	S	S	S	MSI	MSI	MSI	TIP	TIP	TIP	TIP	TIP
15	S	S	S	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP
20	S	S	S	MSI	MSI	TIP	TIP	TIP	TIP	TIP	TIP
25	S	S	S	S	TIP	TIP	TIP	TIP	TIP	TIP	TIP

Table 16 Example of Most Limiting Criteria Distribution - 82-Ft Cutter - Annual Data for East Coast & Gulf Base Criteria Set but with Significant Amplitude Roll Criteria Varied from 4 to 8 to 12 Degrees Low Speed

Roll Criteria = 4 Deg			Roll Criteria = 8 Deg			Roll Criteria = 12 Deg		
ATLANTIC	ANNUAL LOCATION 15.38 -7.50 4.55		ATLANTIC	ANNUAL LOCATION 15.38 -7.50 4.55		ATLANTIC	ANNUAL LOCATION 15.38 -7.50 4.55	
GRID POINT = 401			GRID POINT = 401			GRID POINT = 401		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 38; WPTO = 40	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 65; WPTO = 67	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 67; WPTO = 69
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 40; WPTO = 40	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5% SLAMS 12.5%	PTO = 67; WPTO = 67	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 69; WPTO = 69
GRID POINT = 402			GRID POINT = 402			GRID POINT = 402		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 58; WPTO = 60	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 78; WPTO = 79	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 79; WPTO = 80
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 60; WPTO = 60	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5% SLAMS 12.5%	PTO = 79; WPTO = 79	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 80; WPTO = 80
GRID POINT = 403			GRID POINT = 403			GRID POINT = 403		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 47; WPTO = 49	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 67; WPTO = 68	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 68; WPTO = 69
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 48; WPTO = 49	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5% SLAMS 12.5%	PTO = 68; WPTO = 68	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 70; WPTO = 69
GRID POINT = 405			GRID POINT = 405			GRID POINT = 405		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 32; WPTO = 33	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 50; WPTO = 52	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 52; WPTO = 54
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 33; WPTO = 33	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5% SLAMS 12.5%	PTO = 51; WPTO = 52	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 54; WPTO = 54
GRID POINT = 409			GRID POINT = 409			GRID POINT = 409		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 44; WPTO = 46	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 69; WPTO = 71	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 71; WPTO = 72
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 45; WPTO = 46	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5% SLAMS 12.5%	PTO = 70; WPTO = 71	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 72; WPTO = 72
GRID POINT = 412			GRID POINT = 412			GRID POINT = 412		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 55; WPTO = 57	LIMITING CRITERIA	0 Kts; 66.7% ROLL 33.3%	PTO = 76; WPTO = 77	LIMITING CRITERIA	0 Kts; 100.0%	PTO = 77; WPTO = 78
LIMITING CRITERIA	5 Kts; 100.0%	PTO = 57; WPTO = 57	LIMITING CRITERIA	5 Kts; 50.0% ROLL 37.5%	PTO = 77; WPTO = 77	LIMITING CRITERIA	5 Kts; 83.3% SLAMS 12.5% MSI 4.2%	PTO = 78; WPTO = 78

Table 17 Example of Most Limiting Criteria Distribution - 82-Ft Cutter - Fall Data for Pacific Coast Base Criteria Set but with Significant Amplitude Roll Criteria Varied from 4 to 8 to 12 Degrees High Speed

Roll Criteria = 4 Deg			Roll Criteria = 8 Deg			Roll Criteria = 12 Deg		
PACIFIC	FALL; LOCATION 8.21 0.00 14.05		PACIFIC	FALL; LOCATION 8.21 0.00 14.05		PACIFIC	FALL; LOCATION 8.21 0.00 14.05	
GRID POINT = 610			GRID POINT = 610			GRID POINT = 610		
LIMITING CRITERIA	0 Kts; PTO = 31		LIMITING CRITERIA	0 Kts; PTO = 58		LIMITING CRITERIA	0 Kts; PTO = 58	
ROLL	100.0%		TIPPING	100%		TIPPING	100.0%	
LIMITING CRITERIA	18 Kts; PTO = 41;	WPTO = 43	LIMITING CRITERIA	18 Kts; PTO = 50;	WPTO = 51	LIMITING CRITERIA	18 Kts; PTO = 50;	WPTO = 51
TIPPING	54.2%		TIPPING	70.8%		TIPPING	70.8%	
ROLL	33.3%		SLAMS	16.7%		SLAMS	16.7%	
SLAMS	12.5%		PITCH	12.5%		PITCH	12.5%	
GRID POINT = 611			GRID POINT = 611			GRID POINT = 611		
LIMITING CRITERIA	0 Kts; PTO = 42		LIMITING CRITERIA	0 Kts; PTO = 69		LIMITING CRITERIA	0 Kts; PTO = 69	
ROLL	100.0%		ROLL	100%		TIPPING	100.0%	
LIMITING CRITERIA	18 Kts; PTO = 50;	WPTO = 51	LIMITING CRITERIA	18 Kts; PTO = 58;	WPTO = 58	LIMITING CRITERIA	18 Kts; PTO = 58;	WPTO = 58
TIPPING	54.2%		TIPPING	73.9%		TIPPING	73.9%	
ROLL	33.3%		SLAMS	17.4%		SLAMS	17.4%	
SLAMS	12.5%		PITCH	8.7%		PITCH	8.7%	
GRID POINT = 613			GRID POINT = 613			GRID POINT = 613		
LIMITING CRITERIA	0 Kts; PTO = 38		LIMITING CRITERIA	0 Kts; PTO = 62		LIMITING CRITERIA	0 Kts; PTO = 62	
ROLL	100.0%		ROLL	100%		TIPPING	100.0%	
LIMITING CRITERIA	18 Kts; PTO = 44;	WPTO = 45	LIMITING CRITERIA	18 Kts; PTO = 53;	WPTO = 53	LIMITING CRITERIA	18 Kts; PTO = 53;	WPTO = 53
TIPPING	54.2%		TIPPING	75.0%		TIPPING	75.0%	
ROLL	33.3%		SLAMS	25.0%		SLAMS	25.0%	
SLAMS	12.5%							
GRID POINT = 625			GRID POINT = 625			GRID POINT = 625		
LIMITING CRITERIA	0 Kts; PTO = 73		LIMITING CRITERIA	0 Kts; PTO = 83		LIMITING CRITERIA	0 Kts; PTO = 83	
ROLL	100.0%		TIPPING	100%		TIPPING	100.0%	
LIMITING CRITERIA	18 Kts; PTO = 79;	WPTO = 79	LIMITING CRITERIA	18 Kts; PTO = 81;	WPTO = 81	LIMITING CRITERIA	18 Kts; PTO = 81;	WPTO = 81
TIPPING	54.2%		TIPPING	70.8%		TIPPING	70.8%	
ROLL	29.2%		SLAMS	29.2%		SLAMS	29.2%	
SLAMS	16.7%							

Table 18 Example of Most Limiting Criteria Distribution - 82-Ft Cutter - Annual Data for Atlantic & Gulf of Mexico Base Criteria Set but with Tipping Criteria Varied from 1.05 to 2.1 to 3.15 Tips per Minute, Low Speed

MII (Tip) Criteria = 1.05			MII (Tip) Criteria = 2.1			MII (Tip) Criteria = 3.1		
ATLANTIC GRID POINT = 401	ANNUAL: LOCATION 15 38 -7.50 4.55		ATLANTIC GRID POINT = 401	ANNUAL: LOCATION 15 38 -7.50 4.55		ATLANTIC GRID POINT = 401	ANNUAL: LOCATION 15 38 -7.50 4.55	
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 62; WPTO = 64 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 65; WPTO = 67 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 66; WPTO = 68 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 64; WPTO = 64 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 67; WPTO = 67 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 67; WPTO = 68 70.8% 20.8% 8.3%	
GRID POINT = 402			GRID POINT = 402			GRID POINT = 402		
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 76; WPTO = 77 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 78; WPTO = 79 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 79; WPTO = 80 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 77; WPTO = 77 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 79; WPTO = 79 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 79; WPTO = 80 70.8% 20.8% 8.3%	
GRID POINT = 403			GRID POINT = 403			GRID POINT = 403		
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 65; WPTO = 67 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 67; WPTO = 68 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 68; WPTO = 69 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 67; WPTO = 67 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 68; WPTO = 68 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 68; WPTO = 69 70.8% 20.8% 8.3%	
GRID POINT = 405			GRID POINT = 405			GRID POINT = 405		
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 48; WPTO = 50 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 50; WPTO = 52 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 50; WPTO = 52 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 50; WPTO = 50 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 51; WPTO = 52 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 52; WPTO = 52 70.8% 20.8% 8.3%	
GRID POINT = 409			GRID POINT = 409			GRID POINT = 409		
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 66; WPTO = 67 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 69; WPTO = 71 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 70; WPTO = 71 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 67; WPTO = 67 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 70; WPTO = 71 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 71; WPTO = 71 70.8% 20.8% 8.3%	
GRID POINT = 412			GRID POINT = 412			GRID POINT = 412		
LIMITING CRITERIA - TIPPING	0 Kts; PTO = 74; WPTO = 75 100.0%		LIMITING CRITERIA - TIPPING	0 Kts; PTO = 76; WPTO = 77 66.7%		LIMITING CRITERIA - ROLL	0 Kts; PTO = 76; WPTO = 77 100.0%	
LIMITING CRITERIA - TIPPING SLAMS	5 Kts; PTO = 75; WPTO = 75 87.5% 12.5%		LIMITING CRITERIA - TIPPING ROLL SLAMS	5 Kts; PTO = 77; WPTO = 77 50.0% 37.5% 12.5%		LIMITING CRITERIA - ROLL SLAMS TIPPING	5 Kts; PTO = 77; WPTO = 77 70.8% 20.8% 8.3%	

Table 19 Example of Most Limiting Criteria Distribution - 82-Ft Cutter - Annual Data for Atlantic & Gulf of Mexico Base Criteria Set but with Tipping Criteria Varied from 1.05 to 2.1 to 3.15 Tips per Minute, Economical Speed

MII (Tip) Criteria = 1.05			MII (Tip) Criteria = 2.1			MII (Tip) Criteria = 3.1		
ATLANTIC	ANNUAL: LOCATION 8.21 0.00 14.05		ATLANTIC	ANNUAL: LOCATION 8.21 0.00 14.05		ATLANTIC	ANNUAL: LOCATION 8.21 0.00 14.05	
GRID POINT = 401			GRID POINT = 401			GRID POINT = 401		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 48	LIMITING CRITERIA	0 Kts; 100%	PTO = 53	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 57
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 53			WPTO = 58			WPTO = 61		
GRID POINT = 402			GRID POINT = 402			GRID POINT = 402		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 67	LIMITING CRITERIA	0 Kts; 100%	PTO = 71	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 74
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 71			WPTO = 74			WPTO = 76		
GRID POINT = 403			GRID POINT = 403			GRID POINT = 403		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 57	LIMITING CRITERIA	0 Kts; 100%	PTO = 61	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 64
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 60			WPTO = 64			WPTO = 66		
GRID POINT = 405			GRID POINT = 405			GRID POINT = 405		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 40	LIMITING CRITERIA	0 Kts; 100%	PTO = 45	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 47
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 45			WPTO = 48			WPTO = 50		
GRID POINT = 409			GRID POINT = 409			GRID POINT = 409		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 50	LIMITING CRITERIA	0 Kts; 100%	PTO = 56	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 60
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 58			WPTO = 61			WPTO = 65		
GRID POINT = 412			GRID POINT = 412			GRID POINT = 412		
LIMITING CRITERIA	0 Kts; 100.0%	PTO = 64	LIMITING CRITERIA	0 Kts; 100%	PTO = 69	LIMITING CRITERIA	0 Kts; 87.5%	PTO = 71
TIPPING			TIPPING			TIPPING	12.5%	
SLAMS			SLAMS			SLAMS	4.2%	
WPTO = 68			WPTO = 72			WPTO = 73		

Table 20 Example of Most Limiting Criteria Distribution - 82-Ft Cutter - Annual Data for Atlantic & Gulf of Mexico Base Criteria Set but with Tipping Criteria Varied from 1.05 to 2.1 to 3.15 Tips per Minute, High Speed

MII (Tip) Criteria = 1.05			MII (Tip) Criteria = 2.1			MII (Tip) Criteria = 3.1		
ATLANTIC GRID POINT = 401 LIMITING CRITERIA TIPPING	ANNUAL; LOCATION 8.21 0.00 14.05 18 Kts; 100.0%	PTO = 46	ATLANTIC GRID POINT = 401 LIMITING CRITERIA TIPPING	ANNUAL; LOCATION 8.21 0.00 14.05 18 Kts; 100%	PTO = 53	ATLANTIC GRID POINT = 401 LIMITING CRITERIA TIPPING	ANNUAL; LOCATION 8.21 0.00 14.05 18 Kts; 87.5% 12.5%	PTO = 57
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 57	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 60	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 63
GRID POINT = 402 LIMITING CRITERIA TIPPING	18 Kts; 100.0%	PTO = 67	GRID POINT = 402 LIMITING CRITERIA TIPPING	18 Kts; 100%	PTO = 71	GRID POINT = 402 LIMITING CRITERIA TIPPING	18 Kts; 87.5% 12.5%	PTO = 74
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 71	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 74	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 76
GRID POINT = 403 LIMITING CRITERIA TIPPING	18 Kts; 100.0%	PTO = 57	GRID POINT = 403 LIMITING CRITERIA TIPPING	18 Kts; 100%	PTO = 61	GRID POINT = 403 LIMITING CRITERIA TIPPING	18 Kts; 87.5% 12.5%	PTO = 64
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 62	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 64	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 66
GRID POINT = 405 LIMITING CRITERIA TIPPING	18 Kts; 100.0%	PTO = 40	GRID POINT = 405 LIMITING CRITERIA TIPPING	18 Kts; 100%	PTO = 45	GRID POINT = 405 LIMITING CRITERIA TIPPING	18 Kts; 87.5% 12.5%	PTO = 47
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 48	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 49	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 51
GRID POINT = 409 LIMITING CRITERIA TIPPING	18 Kts; 100.0%	PTO = 50	GRID POINT = 409 LIMITING CRITERIA TIPPING	18 Kts; 100%	PTO = 56	GRID POINT = 409 LIMITING CRITERIA TIPPING	18 Kts; 87.5% 12.5%	PTO = 60
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 61	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 65	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 67
GRID POINT = 412 LIMITING CRITERIA TIPPING	18 Kts; 100.0%	PTO = 64	GRID POINT = 412 LIMITING CRITERIA TIPPING	18 Kts; 100%	PTO = 69	GRID POINT = 412 LIMITING CRITERIA TIPPING	18 Kts; 87.5% 12.5%	PTO = 71
LIMITING CRITERIA TIPPING	18 Kts; 79.2% 20.8%	WPTO = 69	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 71	LIMITING CRITERIA TIPPING	18 Kts; 70.8% 29.2%	WPTO = 73

Table 21 Annual & Winter Weighted Percent Operability Results - All Boats

GRID POINT ANALYSIS ANNUAL DATABASE					GRID POINT ANALYSIS WINTER DATABASE				
	Low Speed	Econ. Speed	Cruising Speed	Combined Effect		Low Speed	Econ. Speed	Cruising Speed	Combined Effect
<u>GP A-405</u>					<u>GP A-405</u>				
CG47	34	46	35	39.175	CG47	18	28	21	22.475
CG82	52	48	50	50.150	CG82	30	29	32	29.725
CG110U	60	56	54	57.850	CG110U	40	36	36	38.000
CG110S	62	63	55	61.900	CG110S	42	45	38	42.975
<u>GP A-412</u>					<u>GP A-412</u>				
CG47	56	69	54	61.375	CG47	50	63	49	55.450
CG82	77	72	72	74.500	CG82	71	65	66	68.075
CG110U	83	78	75	80.275	CG110U	78	73	70	75.275
CG110S	84	84	77	83.475	CG110S	79	80	72	78.900
<u>GP A-402</u>					<u>GP A-402</u>				
CG47	59	71	56	63.875	CG47	52	64	51	57.025
CG82	79	74	74	76.500	CG82	72	67	68	69.575
CG110U	85	80	78	82.350	CG110U	79	74	72	76.400
CG110S	86	86	79	85.475	CG110S	80	81	73	79.900
<u>GP A-403</u>					<u>GP A-403</u>				
CG47	48	61	47	53.450	CG47	38	50	39	43.175
CG82	68	64	64	66.000	CG82	55	52	53	53.575
CG110U	75	71	68	72.775	CG110U	63	59	56	60.775
CG110S	77	77	69	76.400	CG110S	65	66	58	64.900
<u>GP G-409</u>					<u>GP G-409</u>				
CG47	36	54	41	44.025	CG47	28	44	34	35.250
CG82	71	61	65	66.300	CG82	57	50	54	53.800
CG110U	79	73	72	75.925	CG110U	66	61	61	63.500
CG110S	81	82	74	80.900	CG110S	69	71	63	69.400
<u>GP G-401</u>					<u>GP G-401</u>				
CG47	35	53	39	42.950	CG47	29	46	33	36.525
CG82	67	58	61	62.725	CG82	56	49	52	52.725
CG110U	76	70	68	72.850	CG110U	65	59	58	61.925
CG110S	78	79	70	77.825	CG110S	68	69	60	67.825
<u>GP P-610</u>					<u>GP P-610</u>				
CG47	38	51	38	43.525	CG47	30	41	31	34.750
CG82	59	53	50	55.775	CG82	54	46	44	49.850
CG110U	67	58	48	61.750	CG110U	64	51	42	56.825
CG110S	69	63	49	64.950	CG110S	66	57	43	60.450
<u>GP P-613</u>					<u>GP P-613</u>				
CG47	38	50	38	43.100	CG47	40	52	38	44.950
CG82	58	52	49	54.775	CG82	70	59	52	63.975
CG110U	66	57	47	60.750	CG110U	79	63	49	69.950
CG110S	68	62	49	64.025	CG110S	80	68	50	72.650
<u>GP P-611</u>					<u>GP P-611</u>				
CG47	46	58	43	50.875	CG47	49	59	43	52.800
CG82	65	60	55	62.125	CG82	76	66	57	70.325
CG110U	72	63	52	66.675	CG110U	84	69	54	75.375
CG110S	74	67	53	69.450	CG110S	86	73	55	78.150
<u>GP P-625</u>					<u>GP P-625</u>				
CG47	72	80	68	75.100	CG47	73	79	67	75.100
CG82	84	80	78	81.850	CG82	85	80	75	82.125
CG110U	88	83	78	85.125	CG110U	88	82	74	84.400
CG110S	88	86	78	86.400	CG110S	89	84	74	85.750

Table 22 Seasonal Percent Operability Results for the 82-Ft Cutter

	SEASONAL ANALYSIS CG82 CUTTER		
	Low Speed	Econ. Speed	Cruising Speed
<u>WINTER</u>			
GP A-405	30	29	32
GP A-412	71	65	66
GP A-402	72	67	68
GP A-403	55	52	53
GP G-409	57	50	54
GP G-401	56	49	52
GP P-610	54	46	44
GP P-613	70	59	52
GP P-611	76	66	57
GP P-625	85	80	75
<u>SPRING</u>			
GP A-405	50	47	48
GP A-412	76	72	71
GP A-402	78	73	72
GP A-403	66	61	62
GP G-409	67	59	62
GP G-401	64	56	58
GP P-610	58	52	48
GP P-613	53	48	45
GP P-611	60	54	50
GP P-625	76	72	70
<u>SUMMER</u>			
GP A-405	77	71	71
GP A-412	88	80	80
GP A-402	89	83	83
GP A-403	87	81	81
GP G-409	87	75	78
GP G-401	84	72	75
GP P-610	68	65	62
GP P-613	48	47	46
GP P-611	59	57	55
GP P-625	89	86	84
<u>FALL</u>			
GP A-405	50	47	49
GP A-412	76	71	71
GP A-402	78	73	73
GP A-403	64	60	60
GP G-409	72	61	65
GP G-401	63	55	58
GP P-610	59	53	51
GP P-613	63	57	53
GP P-611	70	64	58
GP P-625	86	83	81
<u>ANNUAL</u>			
GP A-405	52	48	50
GP A-412	77	72	72
GP A-402	79	74	74
GP A-403	68	64	64
GP G-409	71	61	65
GP G-401	67	58	61
GP P-610	59	53	50
GP P-613	58	52	49
GP P-611	65	60	55
GP P-625	84	80	78

Table 23 Illustration of Boat Launching Operability when boats operate at 5 knots in seas within deg 30 off stern at Grid Point G-401 and P-610

- (1) DISCRETE - FOR SIGNIFICANT WAVE HEIGHTS IN THE BAND
 (2) CUMULATIVE - FOR SIGNIFICANT WAVE HEIGHTS THROUGH THE BAND

GRID Point G-401		PERCENT TIME OF OCCURRENCE Of Waves in				PERCENT TIME OF OPERATION Boat Launching at 5 kts							
SIGNIFICANT METERS	WAVE HEIGHT FEET	Wave Height Band		47-Ft Unstab		82-Ft Unstab		110-Ft Unstab		Cutter Stab			
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
0.0 - 0.5	0.0 - 1.6	33.7	33.7	100	100	100	100	100	100	100	100	100	100
0.5 - 1.0	1.6 - 3.3	33.7	67.4	81	91	100	100	100	100	100	100	100	100
1.0 - 1.5	3.3 - 4.9	12.8	80.2	64	86	80	97	100	100	100	100	100	100
1.5 - 2.0	4.9 - 6.6	12.8	92.9	48	81	50	90	91	99	100	100	100	100
2.0 - 2.5	6.6 - 8.2	2.6	95.6	69	81	85	90	96	99	98	100	100	100
2.5 - 3.0	8.0 - 9.8	2.6	98.2	29	79	81	90	91	99	95	100	100	100
3.0 - 3.5	9.8 - 11.5	0.6	98.8	0	79	89	90	100	99	100	100	100	100
3.5 - 4.0	11.5 - 13.1	0.6	99.4	0	78	77	90	100	99	100	100	100	100
4.0 - 4.5	13.1 - 14.8	0.2	99.5	0	78	67	90	96	99	100	100	100	100
4.5 - 5.0	14.8 - 16.4	0.2	99.7	0	78	46	90	89	99	100	100	100	100
5.0 - 5.5	16.4 - 18.0	0.2	99.8	0	78	22	90	65	98	83	100	100	100
5.5 - 6.0	18.0 - 19.7	0.2	100.0	0	78	22	89	53	98	64	100	100	100
6.0 - 6.5	19.7 - 21.3	0.0	100.0	0	78	0	89	0	98	0	100	100	100

Grid Point P-610		PERCENT TIME OF OCCURRENCE Of Waves in				PERCENT TIME OF OPERATION Boat Launching at 5 kts							
SIGNIFICANT METERS	WAVE HEIGHT FEET	Wave Height Band		47-Ft Unstab		82-Ft Unstab		110-Ft Unstab		Cutter Stab			
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
0.0 - 0.5	0.0 - 1.6	10.0	10.0	100	100	100	100	100	100	100	100	100	100
0.5 - 1.0	1.6 - 3.3	10.0	20.0	97	98	100	100	100	100	100	100	100	100
1.0 - 1.5	3.3 - 4.9	19.0	38.9	98	98	99	100	100	100	100	100	100	100
1.5 - 2.0	4.9 - 6.6	19.0	57.9	95	97	96	98	100	100	100	100	100	100
2.0 - 2.5	6.6 - 8.2	11.7	69.6	90	96	99	98	100	100	100	100	100	100
2.5 - 3.0	8.2 - 9.8	11.7	81.2	64	92	97	98	100	100	100	100	100	100
3.0 - 3.5	9.8 - 11.5	5.6	86.8	4	86	94	98	100	100	100	100	100	100
3.5 - 4.0	11.5 - 13.1	5.6	92.4	0	81	88	97	99	100	100	100	100	100
4.0 - 4.5	13.1 - 14.8	2.2	94.7	0	79	89	97	99	100	100	100	100	100
4.5 - 5.0	14.8 - 16.4	2.2	96.9	0	77	82	97	96	100	100	100	100	100
5.0 - 5.5	16.4 - 18.0	0.9	97.9	0	76	75	97	89	100	95	100	100	100
5.5 - 6.0	18.0 - 19.7	0.9	98.8	0	75	72	96	85	99	89	100	100	100
6.0 - 6.5	19.7 - 21.3	0.2	99.1	0	75	93	96	100	99	100	100	100	100

Table 24 Summary of Boat Launching Operability when boats operate at 5 knots in seas within 30 degrees off stern at a series of 10 Atlantic, Gulf of Mexico and Pacific Grid Points

NORTH ATLANTIC OCEAN & GULF OF MEXICO - ANNUAL Wave Statistics

GEOGRAPHICAL LOCATION				47-Ft	82-Ft	110-Ft	
GRID POINT	SUB- PROJ.	LAT.	LONG.	Unstab WTED AVER.	Unstab WTED AVER.	Unstab WTED AVER.	Stab. WTED AVER.
A-405	4	42.7	-68.3	65	80	95	98
A-412	4	38.8	-74.6	86	93	99	100
A-402	4	36.9	-75.7	86	93	99	100
A-403	4	30.3	-80.4	80	88	98	99
G-409	4	29.3	-87.5	76	89	98	99
G-401	4	25.9	-89.7	78	89	98	100

NORTH PACIFIC OCEAN - ANNUAL Wave Statistics

P-610	6	46.2	-124.2	75	96	99	100
P-613	6	38.2	-123.3	75	94	99	100
P-611	6	34.9	-120.9	83	97	100	100
P-625	6	33.6	-119.0	93	97	100	100

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APPENDIX A

SMP FREQUENCY RANGES & SMP FUNCTIONS

SMP Frequency Ranges & SMP Functions

SMP91 to SMP'93 Frequency Range Upgrade - For the 1993 USCG Boat Seakeeping Criteria Study

It is necessary when using SMP to calculate ship motions to define both the base range and distribution of wave frequencies for the computed transfer functions. All other required transfer function values at frequencies of the encountered waves are obtained from this basic set by interpolation. Table A-1 shows a comparison between wave period, length and limiting heights. SMP relieves the user the chore of providing this wave frequency information by automatically selecting a suitable range of these wave frequencies. This choice is made on the basis of the natural roll frequency from a set of frequency ranges "built into" the program.

The early versions of SMP, designated as SMP-81 and SMP-84 contained built in just two frequency ranges. The transfer functions at the base frequencies must be calculated with fine enough a resolution to permit a good definition of the narrow banded roll response to be made.

The extensive seakeeping work with the US carriers in 1987 led to the conversion of the US Navy's standard ship motion program SMP-84 as executed on the Carderock's mainframe computer a CDC CYBER 6600 (FORTRAN IV), into a PC (FORTRAN 77) based version. This PC version of SMP, was based on the VAX (FORTRAN 77) version of SMP-84, maintained by NAVSEA Code 03H3 and designated unofficially as SMP-87. This VAX version was used as normal practice by both NAVSEA, CARDEROCKDIV and other US Government agencies in ship design and related studies. It is to be noted that this VAX version of SMP-84 was altered by NAVSEA staff to "improve" the wave frequency range selected automatically for ships with shorter roll periods than those normally associated with carriers or destroyers and frigates and thus became the SMP-87.

In 1991 USCG Buoy Tender design ship motion calculations were performed for USCG by a contractor. This contractor, in accordance with the then standard practice, appropriately employed the VAX version known as SMP-87. Numerical instabilities and other difficulties with the "decks" describing the buoy tender cast some doubt on these contractor's ship motion studies. These studies employed initially the Carderock Code 1561 PC based SMP-87.

The same numerical difficulties encountered by the contractor were then also encountered by the PC based SMP-87. This program used three sets of wave frequency ranges for calculation of the basic transfer functions unlike its predecessors, the mainframe based SMP-84 and SMP-81. It also is to be noted that the two older frequency ranges built into the program, were appropriate for the frigates, destroyers, cruisers and carriers to which SMP had been primarily applied. The 1985-1987 NAVSEA modification of SMP-84 added a third frequency range for smaller ships. The CG's WPB was thus a small ship whose response characteristics represented the outliers of the types of ships for which the ship motion program had been developed and validated.

It was determined, during this 1991 WPB Study that SMP-87 was inappropriate for this ship because the NAVSEA addition to the base sets of wave frequencies did not provide adequate resolution for the WPB's transfer functions, particularly those for roll. These numerical instabilities of the responses, particularly those related strongly to roll were illustrated by erratic variations of the rms responses with consecutive heading values or ship speed. The cause of the numerical instabilities in the rms responses as a function of ship speed and

heading were then traced to an inadequacy of the defined roll transfer function frequency range.

Accordingly as a result of the Quality Assurance work conducted during the 1991 WPB Study, the 1987 PC based SMP-87 forced a revision which was designated as SMP-91 (dated 4/21/91). This revision adopted an appropriate third range of wave frequencies to account for the responses of the much smaller WPB (Buoy Tender) and the shorter wave lengths for which this smaller ship would experience roll resonance.

During the Quality Assurance Phase of the current 1993 USCG Seakeeping Criterion Definition Program for the 47', 82' and 110' cutters, it was noted again that the resolution of roll as well as roll dependent ship motions including particularly vertical accelerations at points away from the centerline was not completely satisfactory. Accordingly therefore, once again, a fourth range of wave frequencies has been incorporated into the Carderock PC version of SMP (SMP-91 - 4/21/91).

The resulting program designated as SMP-93 now contains the four ranges, as shown in Table A-2 and again illustrated in Figure 1, of wave frequencies where the most recent addition was the one required for the CG boats. These ranges are characterized by having suitable distribution of wave frequencies for ranges of roll periods experienced by the various types of ships and boats. The distribution of the wave periods for which the base calculations are made are thus maximized about four ranges of expected waves. Both the maximum resolution period ranges and the total ranges for the four sets of waves are specifically defined as follows:

Type of Ship/Boat			Range of Wave Periods Seconds	Range of Wave Periods Maximum Resolution Seconds
Range #4	USCG Boats		1.57 - 31.4	2.09 - 6.28
Range #3	USCG/USN Small Ships		1.57 - 31.4	6.28 - 12.56
Range #2	Frigates/Destroyers		2.62 - 31.4	10.47 - 15.70
Range #1	Carriers/large ships		3.14 - 31.4	12.56 - 22.43

SMP-93 contains the above set of four frequency ranges 1, 2, 3, 4; where frequency ranges 1 & 2 are identically the same ones contained in SMP-81 and SMP-84 and Range 3 is identically the one added in 1991 to frequency ranges 1 and 2 specifically developed for inclusion into SMP-91 for the CG buoy tender.

Table A-1 Wave Period, Length and Limiting Heights

T SEC	OMEGA RAD/SEC	LAMBDA FT	H7 FT	H25 FT
2.5	2.51	32.04	4.58	1.28
3.1	2.03	49.27	7.04	1.97
3.2	1.96	52.50	7.50	2.10
3.3	1.90	55.83	7.98	2.23
3.5	1.79	62.81	8.97	2.51
3.6	1.74	66.45	9.49	2.65
3.7	1.70	70.19	10.03	2.80
4.1	1.53	86.19	12.31	3.44
4.2	1.50	90.44	12.92	3.61
4.5	1.40	103.80	14.83	4.15
4.8	1.31	118.10	16.88	4.72
6.3	1.00	203.50	29.07	8.14
7.5	0.84	288.40	41.20	11.53
8.6	0.73	379.20	54.17	15.16
9.7	0.65	482.40	68.92	19.29
10.9	0.58	609.10	87.03	24.36
12.4	0.51	788.30	112.63	31.53
13.8	0.46	976.40	139.49	39.05
15.0	0.42	1153.00	164.81	46.14
16.4	0.38	1379.00	197.01	55.16
18.0	0.35	1661.00	237.32	66.45
20.0	0.31	2050.00	292.99	82.03
22.5	0.28	2595.00	370.82	103.82
25.7	0.24	3386.00	483.80	135.46

Table A-2 - Wave Frequency Ranges for SMP-93

Natural Roll Periods Corresponding to different Ranges								
NO Freq	< 5 sec FREQ Range #4		< 9 sec FREQ Range #3		< 15 sec FREQ Range #2		> 15 sec FREQ Range #1	
	OMEGA RAD/SEC	Period SEC	OMEGA RAD/SEC	Period SEC	OMEGA RAD/SEC	Period SEC	OMEGA RAD/SEC	Period SEC
1	0.2	31.40	0.200	31.40	0.200	31.40	0.200	31.40
2	0.4	15.70	0.300	20.93	0.250	25.12	0.250	25.12
3	0.6	10.47	0.400	15.70	0.300	20.93	0.280	22.43
4	0.8	7.85	0.500	12.56	0.350	17.94	0.300	20.93
5	1.0	6.28	0.550	11.42	0.400	15.70	0.320	19.63
6	1.1	5.71	0.575	10.92	0.425	14.78	0.340	18.47
7	1.2	5.23	0.600	10.47	0.450	13.96	0.360	17.44
8	1.3	4.83	0.625	10.05	0.475	13.22	0.380	16.53
9	1.4	4.49	0.650	9.66	0.500	12.56	0.400	15.7
10	1.5	4.19	0.675	9.30	0.525	11.96	0.420	14.95
11	1.6	3.92	0.700	8.97	0.550	11.42	0.440	14.27
12	1.7	3.69	0.725	8.66	0.575	10.92	0.460	13.65
13	1.8	3.49	0.750	8.37	0.600	10.47	0.480	13.08
14	1.9	3.31	0.775	8.10	0.650	9.66	0.500	12.56
15	2.0	3.14	0.800	7.85	0.700	8.97	0.525	11.96
16	2.1	2.99	0.825	7.61	0.750	8.37	0.550	11.42
17	2.2	2.85	0.850	7.39	0.800	7.85	0.575	10.92
18	2.3	2.73	0.900	6.98	0.850	7.39	0.600	10.47
19	2.4	2.62	0.950	6.61	0.900	6.98	0.625	10.05
20	2.5	2.51	1.000	6.28	0.950	6.61	0.650	9.66
21	2.6	2.42	1.100	5.71	1.000	6.28	0.675	9.30
22	2.7	2.33	1.200	5.23	1.100	5.71	0.700	8.97
23	2.8	2.24	1.300	4.83	1.200	5.23	0.750	8.37
24	2.9	2.17	1.500	4.19	1.300	4.83	0.800	7.85
25	3.0	2.09	1.800	3.49	1.400	4.49	0.900	6.98
26	3.2	1.96	2.000	3.14	1.600	3.92	1.000	6.28
27	3.4	1.85	2.500	2.51	1.800	3.49	1.100	5.71
28	3.6	1.74	3.000	2.09	2.000	3.14	1.200	5.23
29	3.8	1.65	3.500	1.79	2.200	2.85	1.500	4.19
30	4.0	1.57	4.000	1.57	2.400	2.62	2.000	3.14

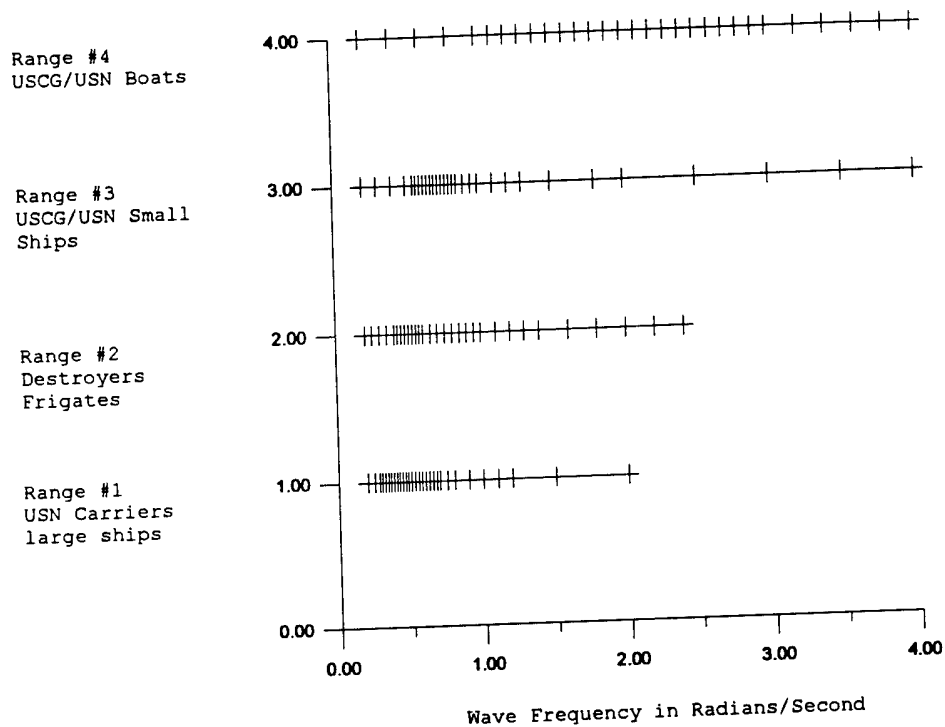


Figure A-1 Wave Frequency Ranges for SMP-93

APPENDIX B

ENVIRONMENTAL DATA FOR CG DATA BASE

Environmental Data for the Seakeeping Evaluation Program

The Seakeeping Evaluation Program (SEP) has been used to estimate the seakeeping performance of surface marine vehicles for many years. The indices of seaworthiness developed in SEP are based on a frequency domain analysis utilizing long term joint occurrence of significant wave height and modal wave period statistics. The wave data in the CG data base are based on the National Oceanic and Atmospheric Administration Data Buoy Center climatic summaries. These summaries provided comprehensive wind and wave data collected for a long period of record from moored buoys and platforms in the near coastal areas adjacent to the US mainland and the deep ocean. All data files have been created from the buoy data. Each SEP input data file has been sorted into significant wave height bands of 0.5 meter and 15 spectral model wave period bands. A methodology has been developed to generate the SEP input files from the buoy climatic summaries and expanded the 5 buoy wave period bands by linear interpretation.

Development of the CG Data Base

A few words are in order in regard to the quality of the buoy data. Since the buoy data are the actual on-site measurements, the wave observational biases of other data base are therefore excluded. The buoy data are probably best used by statistically averaging wave conditions over a period of several years for a specific location and season. Figure B-1 shows a comparison between the US Navy's Spectral Ocean Wave Model grid point 210 and the buoy station 409 annual significant wave height distributions. The agreement between the data base is very good even though they are about 100 miles apart. Figure B-2 shows the locations of buoy stations off the US Eastern and Western coastal areas, and the Gulf of Mexico. A listing of these points with their locations and number of samples is also given in Figure B-2. Both annual and seasonal data are provided. Winter season is defined as December through February. Annual and winter percentage probabilities of occurrence for 10 areas are given in Table B-1 and seasonal data for 3 areas are provided in Table B-2.

There are two shortcomings associated with the buoy data. Buoy data in the summaries are rounded off to the nearest 0.1 percent and the buoy data bandwidths are at least twice as large as the ones required by SEP. Therefore, some arbitrary but systematic small values have been assigned to those that show occurrence but contain less than 0.1 percent of the total data. Furthermore, in order to use the linear interpretation method to expand the data bands, it has been assumed that the buoy data are evenly distributed within each bandwidth. Table B-3 shows the 5 original wave period bands from the buoy summaries and the expanded 15 wave period bands in the CG data base. Table B-4 shows a typical input data file for the SEP. The first line of each data file identifies the location, season and the maximum significant wave height of that buoy location. The cumulative wave data of each location have been sorted into significant wave height bands of 0.5 meter and spectral modal period bands with center periods of 2.5, 3.2, 3.6, 4.2, 4.8, 6.3, 7.5, 8.8, 9.7, 10.9, 12.4, 13.8, 15.0, 16.4, and 18.0 seconds. Two confidence bands used in determining the limiting significant wave heights are included in each data file. The 50 percent and 95 percent confidence bands are those which encompass 50 percent and 95 percent of the data which occur in each significant wave height band.

Spectral Families

Among the various statistical tools to describe the wave field, spectral analysis is the most effective and convenient means. The SOWM and buoy spectra have no inherent biases due to spectral shape and all shapes are sampled. However, it is prohibitively expensive and time consuming to use this large set of spectra for seakeeping performance analysis. This has led to the use of empirical and mathematically derived spectra as a standard tool, even though the idealized spectra have a limited range of applications and may not be realistic in certain situations. Spectra from 4 idealized formulations have been generated for comparison with a typical buoy spectrum from the Kings Bay area. All spectra used the wave statistics in the buoy spectrum which has a significant wave height of 7.8 ft and model wave period of 7.1 sec. Figure B-3 shows the comparison of idealized spectra with buoy derived point spectrum. A short description of the 4 idealized formulations is given below. Figure B-4 shows a map of the Kings Bay area.

Utilizing the measured wave spectra from the North Atlantic, Bretschneider derived the well known two-parameter Bretschneider spectrum applicable to fully developed as well as the usual growing and decaying seas that persist most of the time throughout the world oceans.

The JONSWAP spectrum formulation is developed for fetch-limited North Sea conditions which is fairly similar to the Gulf of Mexico area. When the peakedness parameter equals to 1, the JONSWAP spectrum reduces to the Bretschneider formulation.

Based on the conclusion of the theoretical study on the JONSWAP project and some laboratory results, the Wallops spectrum is derived with the properties of variable bandwidth and correct energy content. One novel feature of the Wallops spectrum is the possibility of using remotely sensed data as an input directly. Wallops spectra represent the less common fully developed as well as the usual partially developed seas that persist most of the time throughout the world oceans. When the slope parameter "m" in the Wallops spectrum decreases to the neighborhood of 5, then the Wallops model will reduce exactly to the Bretschneider spectrum.

The Ochi's six-parameter spectrum, based on the statistical analysis of 800 spectra measured in the North Atlantic ocean, has been traditionally used to model the multiple peaks spectra associated with storm seas. In the derivation of the six-parameter spectrum, the spectrum is decomposed into two parts, one representing the low frequency components and the other the high frequency components of the wave energy. When the shape limit equals to one and with only one component of the spectrum, the three-parameter spectrum will reduce exactly to the Bretschneider spectrum.

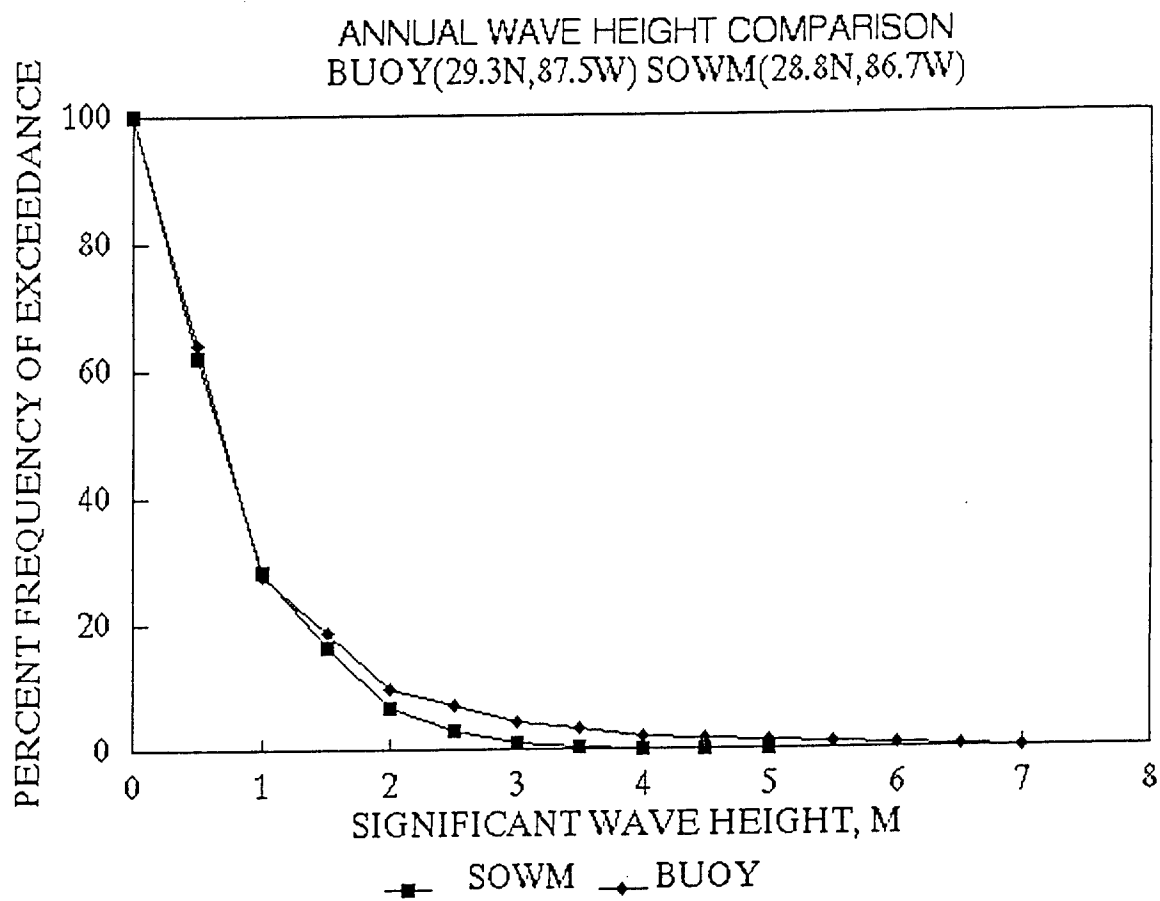
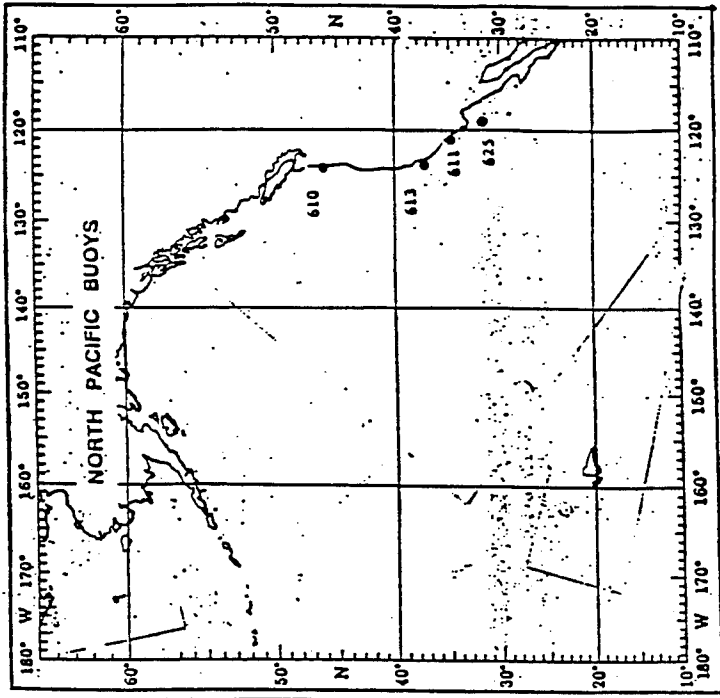
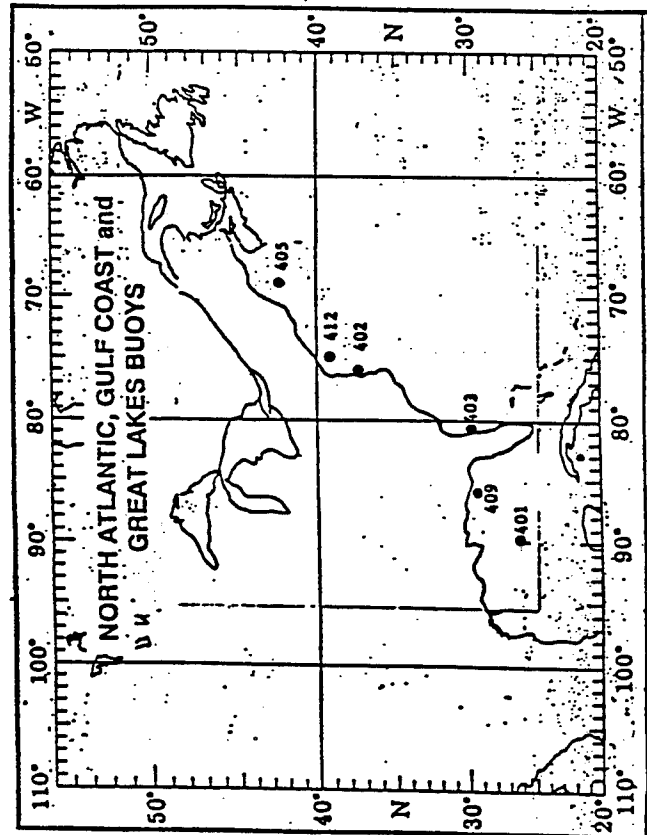


Figure B-1 Comparison of SOWM Data with Buoy Data

Figure B-2 Locations for 1993 CG Wave Data Base

	GRID POINT	SUBPROJECTION	LATITUDE	LONGITUDE	NUMBER OF SAMPLES
ATLANTIC	401	4	25.9 N	89.7 W	65534
	402	4	36.9 N	75.7 W	21863
	403	4	30.3 N	80.4 W	13611
	405	4	42.7 N	68.3 W	66070
	409	4	29.3 N	87.5 W	15831
	412	4	38.8 N	74.6 W	16062
PACIFIC	610	6	46.2 N	124.2 W	55106
	611	6	34.9 N	120.9 W	54304
	613	6	38.2 N	123.3 W	55463
	625	6	33.6 N	119.0 W	53936



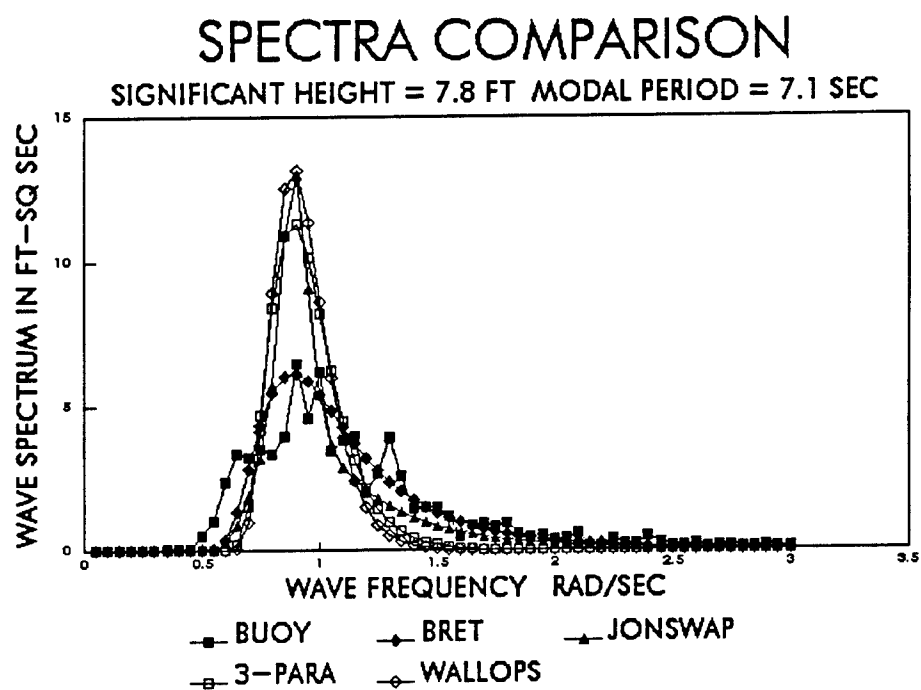


Figure B-3 Comparison of Wave Spectra Models and Measured Data

Figure B-4 Measurement Location for Data used in Comparison of Wave Spectra Models

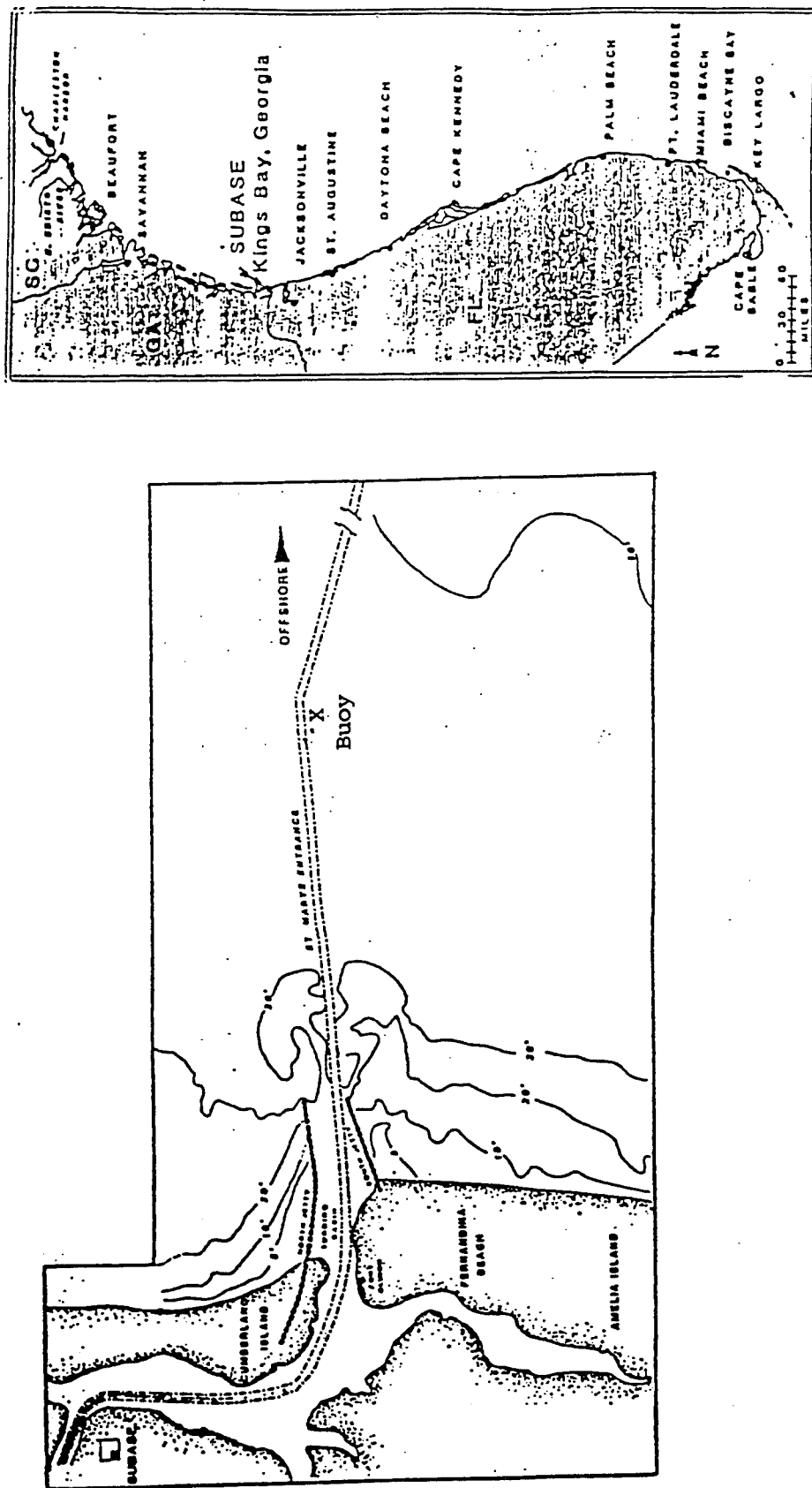


Table B-1 - Annual and Winter Percentage Probabilities of Occurrence for 10 USCG 1993 Boat Series Operational Areas

ANNUAL - GRID POINT 401 LATITUDE 25.9N LONGITUDE 89.7W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	0	0	0	0	0	0	0	0		0
11.6-15.5	0	0	*	*	*	.1	.1	*	*	*		.2
7.6-11.5	.2	2.8	8.2	4.4	1.3	.4	.1	*	*	0		17.5
3.5- 7.5	3.8	56.3	17.1	1.0	*	0	0	0	0	0		78.3
<3.5	.6	3.3	*	0	0	0	0	0	0	0		4.0

GRID POINT 402 LATITUDE 36.9N LONGITUDE 75.7W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.5	*	0	0	*	*	0	0	0		.5
11.6-15.5	0	4.0	1.7	.4	.1	*	0	0	0	0		6.1
7.6-11.5	*	36.3	6.6	1.6	.5	.1	0	0	0	0		45.2
3.5- 7.5	*	33.6	11.6	.9	*	0	0	0	0	0		46.2
<3.5	*	1.9	*	0	0	0	0	0	0	0		2.0

GRID POINT 403 LATITUDE 30.3N LONGITUDE 80.4W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	*	0	0	0	0	0	0	0		*
11.6-15.5	0	.8	1.8	.8	.1	0	0	0	0	0		3.4
7.6-11.5	.1	27.7	12.4	3.3	1.0	0	0	0	0	0		44.6
3.5- 7.5	*	26.3	17.7	2.8	.1	0	0	0	0	0		47.0
<3.5	0	5.0	0	0	0	0	0	0	0	0		5.0

GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.1	*	*	*	*	*	0	0	0		.1
11.6-15.5	0	.5	.8	.7	.5	.2	.1	*	*	*		2.7
7.6-11.5	.1	17.8	11.5	6.5	5.1	2.1	.6	.2	*	*		44.0
3.5- 7.5	.2	23.3	21.6	6.6	.4	.6	.2	*	*	*		52.0
<3.5	.1	1.1	*	*	0	0	0	0	0	0		1.2

GRID POINT 409 LATITUDE 29.3N LONGITUDE 87.5W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	0	0	0	0	0	0	0	0		0
11.6-15.5	0	0	0	0	0	*	*	*	*	*		.1
7.6-11.5	.5	4.8	2.9	2.9	1.5	.2	.1	.1	*	0		12.9
3.5- 7.5	3.5	55.2	15.6	2.5	*	0	0	0	0	0		76.8
<3.5	2.5	7.7	0	0	0	0	0	0	0	0		10.2

GRID POINT 412 LATITUDE 38.8N LONGITUDE 74.6W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.3	*	*	0	0	0	0	0	0		.4
11.6-15.5	0	3.7	1.9	.1	.1	*	*	0	0	0		5.8
7.6-11.5	.2	31.7	8.8	2.4	.7	.1	*	0	0	0		43.8
3.5- 7.5	.2	35.2	12.2	1.1	*	0	0	0	0	0		48.8
<3.5	*	1.2	*	0	0	0	0	0	0	0		1.2

GRID POINT 610 LATITUDE 46.2N LONGITUDE 124.2W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.5	1.1	1.1	.9	.5	.4	.2	.1	*		4.8
11.6-15.5	0	2.2	8.1	9.9	5.5	2.3	1.0	.3	.1	*		29.5
7.6-11.5	*	12.1	25.4	11.8	4.7	1.5	.5	.1	*	*		56.2
6.0- 7.5	*	3.7	3.1	.7	.1	0	0	0	0	0		7.7
<6.0	0	1.4	.5	*	0	0	0	0	0	0		1.8

GRID POINT 611 LATITUDE 34.9N LONGITUDE 120.9W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	1.2	3.3	2.4	1.6	.8	.4	.1	*	*		9.8
11.6-15.5	0	4.8	13.9	9.4	3.4	.9	.2	.1	*	*		32.7
7.6-11.5	0	10.2	24.5	8.9	1.7	.3	.1	0	0	0		45.6
6.0- 7.5	*	1.9	7.5	.8	*	0	0	0	0	0		10.2
<6.0	0	1.1	.6	0	0	0	0	0	0	0		1.7

GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	1.1	2.3	1.8	1.2	.6	.3	.1	*	*		7.5
11.6-15.5	0	3.9	10.5	10.6	4.7	1.2	.2	*	*	*		31.2
7.6-11.5	*	8.5	21.7	12.1	3.5	.6	.1	*	0	0		46.5
6.0- 7.5	0	1.3	6.1	3.7	.2	0	0	0	0	0		11.3
<6.0	0	1.1	2.5	.1	0	0	0	0	0	0		3.6

GRID POINT 625 LATITUDE 33.6N LONGITUDE 119.0W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	8.0	2.2	.6	.2	.1	*	*	*	0		11.0
11.6-15.5	*	25.1	8.8	1.6	.3	*	*	*	*	0		35.7
7.6-11.5	*	16.8	7.7	1.2	.3	*	*	0	0	0		26.0
6.0- 7.5	*	10.9	8.4	1.1	.1	0	0	0	0	0		20.5
<6.0	*	5.7	1.0	*	0	0	0	0	0	0		6.7

* = less than .1%

WINTER - GRID POINT 401 LATITUDE 25.9N LONGITUDE 89.7W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	0	0	0	0	0	0	0	0		0
11.6-15.5	0	0	0	0	0	*	*	*	*	0		.1
7.6-11.5	0	2.3	12.0	7.3	2.6	.7	.2	*	0	0		25.0
3.5- 7.5	.4	46.7	24.2	2.0	*	0	0	0	0	0		73.2
<3.5	0	1.6	*	0	0	0	0	0	0	0		1.7

GRID POINT 402 LATITUDE 36.9N LONGITUDE 75.7W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.2	*	0	0	0	0	0	0	0		.3
11.6-15.5	0	2.3	1.7	.5	.1	.1	0	0	0	0		4.7
7.6-11.5	.1	30.2	8.6	2.4	.9	.1	0	0	0	0		42.3
3.5- 7.5	0	31.6	16.3	1.8	.1	0	0	0	0	0		49.9
<3.5	.1	2.7	0	0	0	0	0	0	0	0		2.8

GRID POINT 403 LATITUDE 30.3N LONGITUDE 80.4W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	*	0	0	0	0	0	0	0		*
11.6-15.5	0	1.0	4.1	.2	0	0	0	0	0	0		5.4
7.6-11.5	0	18.5	14.4	5.8	2.0	0	0	0	0	0		40.6
3.5- 7.5	0	18.2	24.7	6.2	.2	0	0	0	0	0		49.3
<3.5	0	4.7	0	0	0	0	0	0	0	0		4.7

GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	0	0	*	0	*	0	0	0		*
11.6-15.5	0	.3	.8	1.0	1.0	.4	.2	.1	*	0		3.9
7.6-11.5	0	6.1	9.1	9.6	9.3	4.9	1.3	.4	.1	0		41.0
3.5- 7.5	*	12.8	28.6	12.2	.8	*	0	*	0	0		54.5
<3.5	0	.7	*	*	0	0	0	0	0	0		.7

GRID POINT 409 LATITUDE 29.3N LONGITUDE 87.5W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	0	0	0	0	0	0	0	0	0		0
11.6-15.5	0	0	0	0	0	*	.1	.1	.1	*		.3
7.6-11.5	0	2.4	3.1	5.6	3.8	.8	.2	.3	.1	0		16.2
3.5- 7.5	2.4	42.9	23.0	5.4	.1	0	0	0	0	0		73.8
<3.5	1.9	7.8	0	0	0	0	0	0	0	0		9.7

GRID POINT 412 LATITUDE 38.8N LONGITUDE 74.6W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	1.0	.2	.1	0	0	0	0	0	0		1.3
11.6-15.5	0	5.6	3.2	.3	.3	.1	*	0	0	0		9.6
7.6-11.5	.4	21.9	6.9	2.6	.9	.2	*	0	0	0		33.0
3.5- 7.5	.1	34.2	18.3	1.5	.1	0	0	0	0	0		54.2
<3.5	0	1.9	0	0	0	0	0	0	0	0		1.9

GRID POINT 610 LATITUDE 46.2N LONGITUDE 124.2W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.1	1.8	1.7	1.5	1.2	.7	.4	.2	.1		7.7
11.6-15.5	0	2.7	11.6	14.9	8.9	4.3	2.2	.8	.3	.1		45.7
7.6-11.5	0	4.3	12.8	13.9	7.5	2.7	1.0	.2	.1	*		42.4
6.0- 7.5	*	.2	1.1	.9	.1	0	0	0	0	0		2.3
<6.0	0	1.4	.5	*	0	0	0	0	0	0		1.9

GRID POINT 611 LATITUDE 34.9N LONGITUDE 120.9W

WAVE PERIOD (SEC)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	...	TOTAL
>15.5	0	.6	4.8	6.0	4.0	2.6	1.4	.4	*	*		19.9
11.6-15.5	0	5.0	23.7	18.0	6.9	2.2	.6	.2	*	*		56.7
7.6-11.5	0	4.8	10.1	4.1	1.1	.3	.1	0	0	0		20.4
6.0- 7.5	0	.4	1.4	.4	.1	0	0	0	0	0		2.3
<6.0	0	.3	.4	0	0	0	0	0	0	0		.6

GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W

>15.5	0	.4	2.8	4.8	3.3	1.7	.7	.3	*	*	14.0
11.6-15.5	0	3.7	17.4	20.5	9.7	2.7	.4	.1	*	*	54.6
7.6-11.5	0	4.7	11.5	7.5	2.6	.6	.2	.1	0	0	27.1
6.0- 7.5	0	.9	1.0	1.1	.1	0	0	0	0	0	3.2
<6.0	0	.4	.6	*	0	0	0	0	0	0	1.0

Table B-2 Seasonal Percentage Probabilities of Occurrence for 3 USCG 1993
Boat Series Operational Areas

ANNUAL GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.1	*	*	*	*	*	0	0	0		1
11.6-15.5	0	.5	.8	.7	.5	.2	.1	*	*	*		2.7
7.6-11.5	.1	17.8	11.5	6.5	5.1	2.1	.6	.2	*	*		44.0
3.5-7.5	.2	23.3	21.6	6.6	.4	.6	.2	*	*	*		52.0
<3.5	.1	1.1	*	*	0	0	0	0	0	0		1.2
WINTER GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	0	0	0	0	0	0	0	0	0		*
11.6-15.5	0	.3	.8	1.0	1.0	.4	.2	.1	*	0		3.9
7.6-11.5	0	6.1	9.1	9.6	9.3	4.9	1.3	.4	.1	0		41.0
3.5-7.5	*	12.8	28.6	12.2	.8	*	0	*	0	0		54.5
<3.5	0	.7	*	*	0	0	0	0	0	0		7
SPRING GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	0	0	0	0	0	0	0	0	0		*
11.6-15.5	0	.2	.8	.8	.4	.2	*	*	*	1		2.5
7.6-11.5	*	19.2	16.5	9.1	5.7	2.0	.8	.2	*	*		53.6
3.5-7.5	0	17.5	18.5	6.5	.5	0	0	0	0	0		43.0
<3.5	.1	.8	*	*	0	0	0	0	0	0		9
SUMMER GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.2	*	0	0	0	0	0	0	0		2
11.6-15.5	0	.4	.4	.1	*	0	0	0	0	0		9
7.6-11.5	.5	30.8	8.9	1.6	.7	.1	*	0	0	0		42.6
3.5-7.5	.6	40.1	12.5	1.0	*	0	0	0	0	0		54.3
<3.5	.3	1.7	0	0	0	0	0	0	0	0		1.9
FALL GRID POINT 405 LATITUDE 42.7N LONGITUDE 68.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	0	0	*	0	*	0	0	0	0		*
11.6-15.5	0	1.0	1.0	.9	.5	.1	*	*	0	0		3.6
7.6-11.5	*	15.7	12.0	5.9	4.4	1.3	.4	.1	*	0		39.8
3.5-7.5	*	22.4	26.1	6.3	.3	0	0	0	0	0		55.2
<3.5	*	1.3	0	0	0	0	0	0	0	0		1.4
ANNUAL GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.5	1.1	1.1	.9	.5	.4	.2	.1	*		4.8
11.6-15.5	0	2.2	8.1	9.9	5.5	2.3	1.0	.3	.1	*		29.5
7.6-11.5	*	12.1	25.4	11.8	4.7	1.5	.5	.1	*	*		56.2
3.5-7.5	*	3.7	3.1	.7	.1	0	0	0	0	0		7.7
<3.5	0	1.4	.5	*	0	0	0	0	0	0		1.8
WINTER GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.1	1.8	1.7	1.5	1.2	.7	.4	.2	.1		7.7
11.6-15.5	0	2.7	11.6	14.9	8.9	4.3	2.2	.8	.3	.1		45.7
7.6-11.5	0	4.3	12.8	13.9	7.5	2.7	1.0	.2	.1	*		42.4
3.5-7.5	*	.2	1.1	.9	.1	0	0	0	0	0		2.3
<3.5	0	1.4	.5	*	0	0	0	0	0	0		1.9
SPRING GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.1	1.0	2.0	1.5	.3	.2	*	0	0		5.1
11.6-15.5	0	1.8	9.1	13.2	5.0	1.9	.5	.1	*	*		31.6
7.6-11.5	0	9.1	29.0	14.1	4.7	1.0	.3	.1	*	0		58.2
3.5-7.5	0	1.0	2.4	.9	.2	0	0	0	0	0		4.5
<3.5	0	.4	.2	*	0	0	0	0	0	0		.7
SUMMER GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	1.4	.4	*	0	0	0	0	0	0		1.8
11.6-15.5	0	2.7	2.7	1.5	.2	*	0	0	0	0		7.1
7.6-11.5	0	22.6	36.6	7.0	.2	0	0	0	0	0		66.4
3.5-7.5	0	13.1	7.7	.2	*	0	0	0	0	0		21.1
<3.5	0	2.8	.7	0	0	0	0	0	0	0		3.6
FALL GRID POINT 613 LATITUDE 38.2N LONGITUDE 123.3W												Tot%
Wave Per. (Sec)	00	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0		
>15.5	0	.6	1.2	.5	.6	.4	.4	.2	.1	*		4.0
11.6-15.5	0	1.8	7.5	8.4	6.0	2.3	1.0	.4	.1	*		27.5
7.6-11.5	*	14.8	28.9	11.4	4.9	1.7	.5	.1	0	0		60.4
3.5-7.5	0	2.9	2.7	.7	.2	0	0	0	0	0		6.5
<3.5	0	1.1	.5	0	0	0	0	0	0	0		1.6

* = less than .1%

Table B-3 Wave Period Bands for SEP-93 (1993 USCG Boat Series)

CG DATA BASE

The wind and wave data bases selected for this study is the National Oceanic and Atmospheric Administration Data Buoy Center climatic summaries. There are only 5 wave period bands in the buoy data. However, 15 modal wave period bands are needed for the Seakeeping Evaluation Program (SEP). Therefore, by linear interpolation, buoy data in the 5 wave period bands have been expanded to 15 wave period bands for SEP.

WAVE PERIOD BANDS FOR SEP			
	BUOY DATA (SEC)	VERSION I (SEC)	VERSION II (SEC)
	> 15.5	16.4,18.0,20.0,22.5,25.7	16.4,18.0
ATLANTIC	11.6-15.5	12.4,13.8,15.0	12.4,13.8,15.0
	7.6-11.5	8.8,9.7,10.9	8.8,9.7,10.9
	3.5-7.5	4.8,6.3,7.5	3.6,4.2,4.8,6.3,7.5
	<3.5	3.2	2.5,3.2

WAVE PERIOD BANDS FOR SEP			
	BUOY DATA (SEC)	VERSION I (SEC)	VERSION II (SEC)
	> 15.5	16.4,18.0,20.0,22.5,25.7	16.4,18.0
PACIFIC	11.6-15.5	12.4,13.8,15.0	12.4,13.8,15.0
	7.6-11.5	8.8,9.7,10.9	8.8,9.7,10.9
	6-7.5	6.3,7.5	6.3,7.5
	<6	3.2,4.8	2.5,3.2,3.6,4.2,4.8

	2	4	405	42.70000	-68.30000	0.0	ANNUAL
0.0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.5	0.25000	0.25000	2.35072	2.35072	2.35072	2.95009	0.00000
1.0	0.50000	0.50000	4.70131	4.70131	4.70131	5.90116	5.90116
1.5	0.75000	0.75000	7.05187	7.05187	7.05187	8.70174	8.70174
2.0	1.00000	1.00000	9.40243	9.40243	9.40243	11.40289	11.40289
2.5	1.25000	1.25000	11.75299	11.75299	11.75299	14.10354	14.10354
3.0	1.50000	1.50000	14.10354	14.10354	14.10354	16.80419	16.80419
3.5	1.75000	1.75000	16.45410	16.45410	16.45410	19.50484	19.50484
4.0	2.00000	2.00000	18.80465	18.80465	18.80465	22.20549	22.20549
4.5	2.25000	2.25000	21.15520	21.15520	21.15520	24.90614	24.90614
5.0	2.50000	2.50000	23.50575	23.50575	23.50575	27.60679	27.60679
5.5	2.75000	2.75000	25.85630	25.85630	25.85630	30.30744	30.30744
6.0	3.00000	3.00000	28.20685	28.20685	28.20685	33.00809	33.00809
6.5	3.25000	3.25000	30.55740	30.55740	30.55740	35.70874	35.70874
7.0	3.50000	3.50000	32.90795	32.90795	32.90795	38.40939	38.40939
7.5	3.75000	3.75000	35.25850	35.25850	35.25850	41.11004	41.11004
8.0	4.00000	4.00000	37.60905	37.60905	37.60905	43.81069	43.81069
8.5	4.25000	4.25000	39.95960	39.95960	39.95960	46.51134	46.51134
9.0	4.50000	4.50000	42.31015	42.31015	42.31015	49.21199	49.21199
9.5	4.75000	4.75000	44.66070	44.66070	44.66070	51.91264	51.91264
10.0	5.00000	5.00000	47.01125	47.01125	47.01125	54.61329	54.61329
10.5	5.25000	5.25000	49.36180	49.36180	49.36180	57.31394	57.31394
11.0	5.50000	5.50000	51.71235	51.71235	51.71235	60.01459	60.01459
11.5	5.75000	5.75000	54.06290	54.06290	54.06290	62.71514	62.71514
12.0	6.00000	6.00000	56.41345	56.41345	56.41345	65.41579	65.41579
12.5	6.25000	6.25000	58.76400	58.76400	58.76400	68.11644	68.11644
13.0	6.50000	6.50000	61.11455	61.11455	61.11455	70.81709	70.81709
13.5	6.75000	6.75000	63.46510	63.46510	63.46510	73.51774	73.51774
14.0	7.00000	7.00000	65.81565	65.81565	65.81565	76.21839	76.21839
14.5	7.25000	7.25000	68.16620	68.16620	68.16620	78.91904	78.91904
15.0	7.50000	7.50000	70.51675	70.51675	70.51675	81.61969	81.61969
15.5	7.75000	7.75000	72.86730	72.86730	72.86730	84.32034	84.32034
16.0	8.00000	8.00000	75.21785	75.21785	75.21785	87.02099	87.02099
16.5	8.25000	8.25000	77.56840	77.56840	77.56840	89.72164	89.72164
17.0	8.50000	8.50000	79.91895	79.91895	79.91895	92.42229	92.42229
17.5	8.75000	8.75000	82.26950	82.26950	82.26950	95.12294	95.12294
18.0	9.00000	9.00000	84.62005	84.62005	84.62005	97.82359	97.82359
18.5	9.25000	9.25000	86.97060	86.97060	86.97060	100.52414	100.52414
19.0	9.50000	9.50000	89.32115	89.32115	89.32115	103.22479	103.22479
19.5	9.75000	9.750					

APPENDIX C

SHIP/BOAT MOTION DETAILS

Ship Motions

Ship motions were computed using the existing standard ship motion program validated and documented for US Navy surface ships. This program, known as SMP (see references 12 and 13), was modified and designated as SMP93-PC (see references 24 and 25) to account for the differences in the wave frequencies important in the dynamics of ships and boats as discussed in Appendix A.

Figure C-1 presents the scaled outboard profile for the three boats examined in this study along with the three locations of particular interest on all three boats. The three locations of interest for the purposes of determining the absolute ship motions and their impact on crew and equipment are shown as three numbers i.e. 1, 2 and 3. Location 1 corresponds to the pilot house where the crew operating the boat is stationed during the transit, location 2 corresponds to the location where nominally the crew can/could rest; and location 3 is the location where the mission critical boat launching operations are to occur once the boat has reached its operating area. It is apparent from these scaled sketches of the boats that the three location of interest for the seakeeping investigation of these boats is not in the same relative locations on the three boats. Additional details on the particulars of the boats are provided in the main text figure 1 as well as tables 4 and 5.

Boat/Ship Motion Characteristics

For comparison purposes the motion characteristic of ships and boats are contrasted in a series of steps. Initially, the responses of the boats/ships are discussed in terms of their transfer functions for boats, then for contrast for ships and finally the three primary motions of roll, pitch and heave are presented for the three boats. Next the components of the motions are discussed and their relative magnitude is compared based on simulated motions-at-a-point time histories.

Transfer Functions

Monohull boat and ship roll tend to have relatively narrow frequency band responses which are characteristic of low damped second order equations of motions. Figure C-2 illustrates typical roll responses predicted with SMP-93PC for the 47-ft boat at low speed in bow seas. This data is shown in non-dimensional transfer function form to permit ready comparison of these responses to those of other larger boats and surface ships. The roll response is shown on the vertical axis of the figure as the ratio of the roll amplitude to the underlying wave slope which caused the response. In this presentation larger roll corresponds to larger values of the roll to wave slope ratio. Wave frequency is shown on the horizontal axis as the ratio of the wave length to the ship or boat length. Here the wave length increases obviously to the right as the wave length to ship length ratio increases.

The example roll transfer function of Figure C-2 demonstrates that as the wave length decrease below the resonant or maximum roll at a value ranging between 2.5 and 3, roll decreases to zero with decreasing wave length. However as the waves get longer than those which produce the

resonant rolling, the roll values fall off somewhat slower to nearly steady value of 1.00 which in turn corresponds to the value of the wave slope. In short, in the longer waves the 47 ft cutter's roll motions approach the wave slope. This behavior of the boat motions is known as wave contouring. Roll is greater than the wave slope over a range that starts at about a wave length to ship length ratio of about 1.5 and extends to at least a wave length to ship length of 10. In this range roll is clearly amplified by the boat's dynamic behavior. The resonant roll is in fact almost two and a half times the magnitude of the wave slope. This range of roll motions thus corresponds to the range where boat dynamics govern roll responses. This range is designated as the dynamic roll range of the boat. It is over this range of waves and thus roll responses where the roll of the ship can be modified by design of the hull and its appendage suite and with the introduction of devices which increase roll damping.

Figure C-3 contrasts the predicted roll responses of an aircraft carrier as well as experimentally determined roll of a relatively small destroyer escort. Compare these roll responses of larger ships with the roll responses of the 47-ft cutter. Ship transfer function results are again shown in the same non-dimensional format as was the case for the boat. Attention is to be focused on dynamic roll ranges for both the carrier and the destroyer escort. Clearly the dynamic roll of the carrier operating at 0 knots in beam seas was very much more highly tuned and thus sensitive to variations in wave length than is the case for either the 47 ft boat or the destroyer escort. Clearly the dynamic range of roll for the carrier is for all intents and purposes, contained within the band of wave lengths that range from 0.4 to about 3 times ship length. It is evident that the roll response of the carrier is in fact very much greater at resonance than is the case for the boats. The carrier roll being on the order of 10 to 15 times the wave slope whereas the boat roll is on the order of only 2.3 times wave slope. In the case of the destroyer escort, the dynamic range of roll is similarly restricted to that of the carrier though the value of the roll response is much closer with transfer function values at roll resonance ranging from about 4 to 5 times the wave slope. As an aside, the measured destroyer escort data is presented with the heading convention also used in the SEP program which defined head seas as being 180 degrees, beam seas as 90 degrees and following seas as 0 degrees. This measured destroyer escort data also illustrates the effect of heading on the transfer functions of roll, pitch and heave. It is evident that only roll shows the sharp dynamic responses in the vicinity of beam seas.

Figure C-4 was prepared to illustrate a comparison at 8 knots in 60 degree bow waves between the roll, pitch and heave responses of the three boats. The data is provided in the same transfer function response format as was provided in Figures C-2 and C-3. As for roll, the pitch response was non-dimensionalized with the wave slope causing the pitch. Heave in turn was non-dimensionalized by dividing heave amplitude by the wave amplitude which caused heave. For the record, the vertical motion of the ships CG is defined as heave. When the three boats are compared the smallest boat has the lowest resonant roll response of the three vessels although it also has the widest dynamic roll range. In effect then this roll transfer function behavior illustrates that the smallest boat will respond to the widest range of waves. The heave response of all three boats reach their quasi-static value which equals the wave height at wave

lengths less than the boat length. For longer waves all three boats exhibit the same heave response i.e. the heave being equal to wave height. The pitch response of all three boats behave similar to heave in that they reach the quasi static wave contouring value of the wave slope once waves longer than boat length are encountered. This figure thus illustrates some of the basic motion characteristics of boats at the economical cruising speed in bow seas.

Figure C-4b was prepared to illustrate at this speed the heading response characteristics of the boats. In head seas, (0 degrees) the transfer functions of all three boats are very similar for roll pitch and heave. As heading varies towards beam seas, heave stays largely unaffected by the heading variation. However both the angular responses vary strongly with heading. As the heading varies towards beam seas, the stiff-in roll boats approach their resonant roll responses whereas the pitch response of the boats decreases as a function of the cosine of heading until at beam seas pitch is zero.

Figure C-4c was prepared to illustrate systematically the speed effect on roll, pitch and heave in bow seas for the three boats. The resonant roll behavior of the boats is most pronounced at zero speed and then decreases continuously as speed increases. In general the dynamic range of roll increases with increasing speed. The 47-ft boats resonant roll responses decrease more than is the case for the larger 82-ft and 110-ft cutters. This behavior for both the larger boats suggests that roll responses will be a nearly constant with ship speed whereas they will drop off much more with speed for the smallest boat. The heave and pitch behavior illustrated for these three boats operating in bow seas demonstrates that these responses will be very similar for all three boats and not subject to modification by hull design except with the introduction of anti-pitch fins.

Natural Motion Period of Ships and Boats

The definition of the natural roll, pitch and heave periods correspond to the peak of the zero speed, transfer functions in beam seas for roll and heave displacement and in head seas for pitch. The natural ship motion period data results obtained by this technique are shown for a variety of typical naval ships including the small USCG boats under consideration in this study are shown in Table 6. One evident result from a glance at these natural motion periods is the trend for natural periods of the larger ships to get longer. Another observation of this data indicates that the heave periods of the carriers, auxiliaries, destroyers and frigates are always much shorter than the pitch and the roll periods. In fact, when the heave periods are compared to the roll periods, the differences are greater than a factor of 2 except for the very unusual, stiff-in-roll former CV41. When the USCG boats natural periods are examined it becomes apparent that the differences between the individual natural response periods are only the order of one second or less with the exception of the 47-ft boats apparent heave natural period.

In contrast to larger ships, boats tend to be very stiff due to roll stability requirements. These result because of the boats small sizes relative to the encountered waves. Thus boats tend to have proportionally shorter roll periods than ships and this in turn increases the level of the roll associated accelerations. It is important to recognize that the

boats are different from the ships because they are essentially shorter and stiffer in roll than ships. Thus boats encounter all of their motion natural periods and maximum responses at the shorter periods and thus also the shorter, more frequently occurring waves than waves which would tend to produce large ship motions.

It is to be expected that ship/boat responses that result from a combination of the basic components of the 6 degree of freedom motions of ships/boats will exhibit different characteristics as the natural periods associated with the components vary. To further contrast boat and ship responses the combination of ship responses into the responses at arbitrary points are discussed next.

Ship Motion Definitions at Arbitrary Points on the Ship/Boat

The basic 6 degrees of ship motions consist of three linear and three angular motions. From these basic motions referenced to the origin all other ship required motion responses were calculated. The origin of the SMP co-ordinate system is the Longitudinal Center of Gravity, LCG, in the waterplane of the ship.

The three linear displacements in the x, y and z directions are defined respectively as surge, sway and heave. In SMP, positive surge is forward, positive sway is to port and positive heave is up. The three angular motions about the x, y and z axes are defined as roll, pitch and yaw. Positive roll is starboard side down, positive pitch is bow down and positive yaw is bow to port. The origin of SMP's right handed coordinate system is at the longitudinal center of gravity in the waterplane. This origin moves forward at the mean speed of the ship.

When the ship is regarded as a rigid, nonflexing body, the linear displacements for any location on the ship are obtained from the 6 degree of freedom motions by:

$$x = \text{surge} - y\text{bar} \cdot \text{yaw} + z\text{bar} \cdot \text{pitch}$$

$$y = \text{sway} - z\text{bar} \cdot \text{roll} + x\text{bar} \cdot \text{yaw}$$

$$z = \text{heave} - x\text{bar} \cdot \text{pitch} + y\text{bar} \cdot \text{roll}$$

where xbar, ybar and zbar are the moment arms in feet from the origin of the coordinate system at the LCG in the waterplane.

Angular ship motions of course are the same at any point on the ship. The linear ship motions on the other hand as can be noted from the above expression vary as a function of the position on the ship. Linear velocities, or accelerations at any point of the ship can of course be obtained by single or double differentiation respectively. Thus the ship induced acceleration forces acting on the crew and shipboard equipment at arbitrary points are mixtures of angular motions times moment arms and the pure linear motion.

Figures C-5 through C-7 were prepared to expand on the implications of the differences in the natural periods for boats and ships. A 60

minute duration time domain simulation of the 82-ft cutter operating in 2.6 ft significant wave height seas with a 5 second modal wave period was performed. This simulation had the boat operating at 5 knots at a heading with the seas coming 60 degrees off the starboard bow. The seas were simulated as shortcrested Brestschneider spectra. This simulation was performed to illustrate the magnitude of the individual components of the vertical accelerations. The components of vertical acceleration at the boat launch deck edge location, DE Vert Acc are shown in accordance with the expression

$$\text{DE Vert Acc} = \text{Heave Acc} - \bar{x} \cdot \text{Pitch Acc} + \bar{y} \cdot \text{Roll Acc}$$

Figure C-5a illustrates the effect on vertical acceleration of a 7.5 foot lateral shift in the location at the boat launch position. Two acceleration components are shown. These are designated as the deck edge vertical acceleration, DE Vert Acc and the centerline vertical acceleration, CL Vert Acc.

$$\text{CL Vert Acc} = \text{Heave Acc} - \bar{x} \cdot \text{Pitch Acc}$$

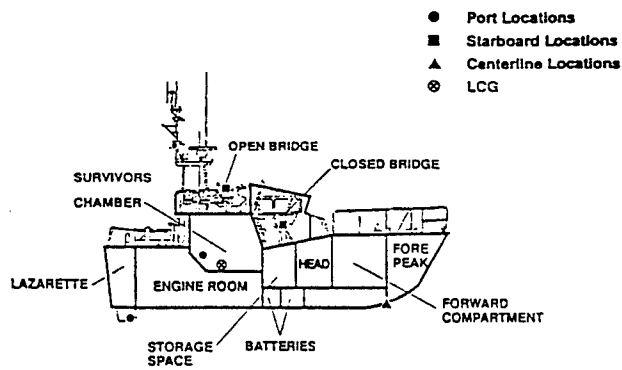
Clearly the DE Vert Acc is significantly larger than the CL Vert Acc. It is to be noted however, that these two components differ only in the contribution due to roll brought about by the 7.5 ft lateral shift, $\bar{y} \cdot \text{Roll Acc}$.

Figure C-5b illustrates in addition to the DE Vert Acc the heave acceleration term, Heave Acc as well as the roll acceleration contribution, $\bar{y} \cdot \text{Roll Acc}$. The Heave Acc component is in fact smaller than the $\bar{y} \cdot \text{Roll Acc}$. In short roll is a more important term in the boat launch operation for this example than is the case for heave.

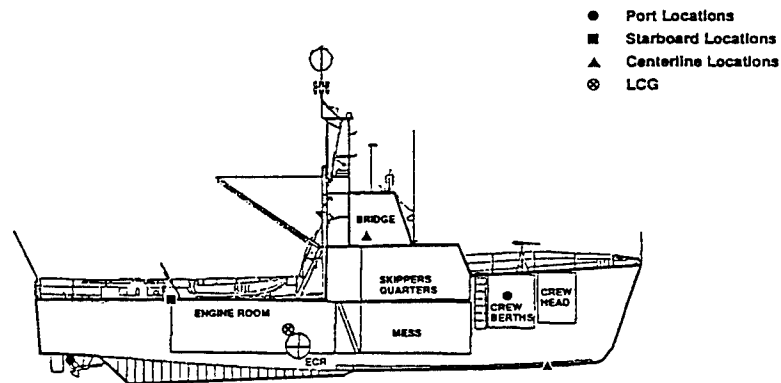
Figure C-5c illustrates the relative magnitude of the pitch acceleration and the roll acceleration terms i.e. $\bar{x} \cdot \text{Pitch Acc}$, and $\bar{y} \cdot \text{Roll Acc}$. Again, this data illustrates that roll is a larger component in this example than is pitch.

Figure C-6a illustrates in power spectral format the difference in the vertical acceleration at the deck edge and on the centerline of the ship at the boat launch location. Figure C-6a thus illustrates that a simple lateral shift of 7.5 feet will increase dramatically the exposure of the crew to vertical accelerations. For example, refer the cycles of severe vertical accelerations (see main text for definition) tabulated for the centerline and the deck edge locations. Within a 20 minute time duration, the centerline location will experience only 3 of these acceleration cycles above levels of 0.15g whereas the deck edge location will experience 101 such cycles.

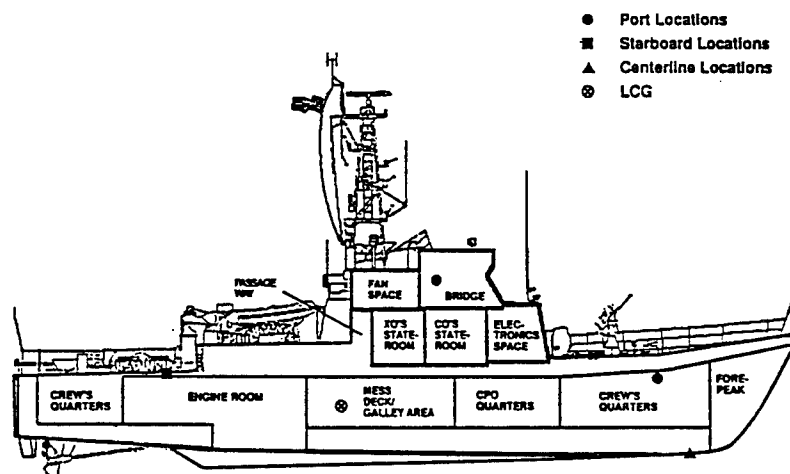
Figure C-6b illustrates the relative magnitudes of the roll and pitch of the 82-ft cutter at these moderate speeds and low seas.



OUTBOARD PROFILE OF CG47



OUTBOARD PROFILE OF CG82



OUTBOARD PROFILE OF CG110

Figure C-1 Outboard Profile of 1993 USCG Seakeeping Boat Series

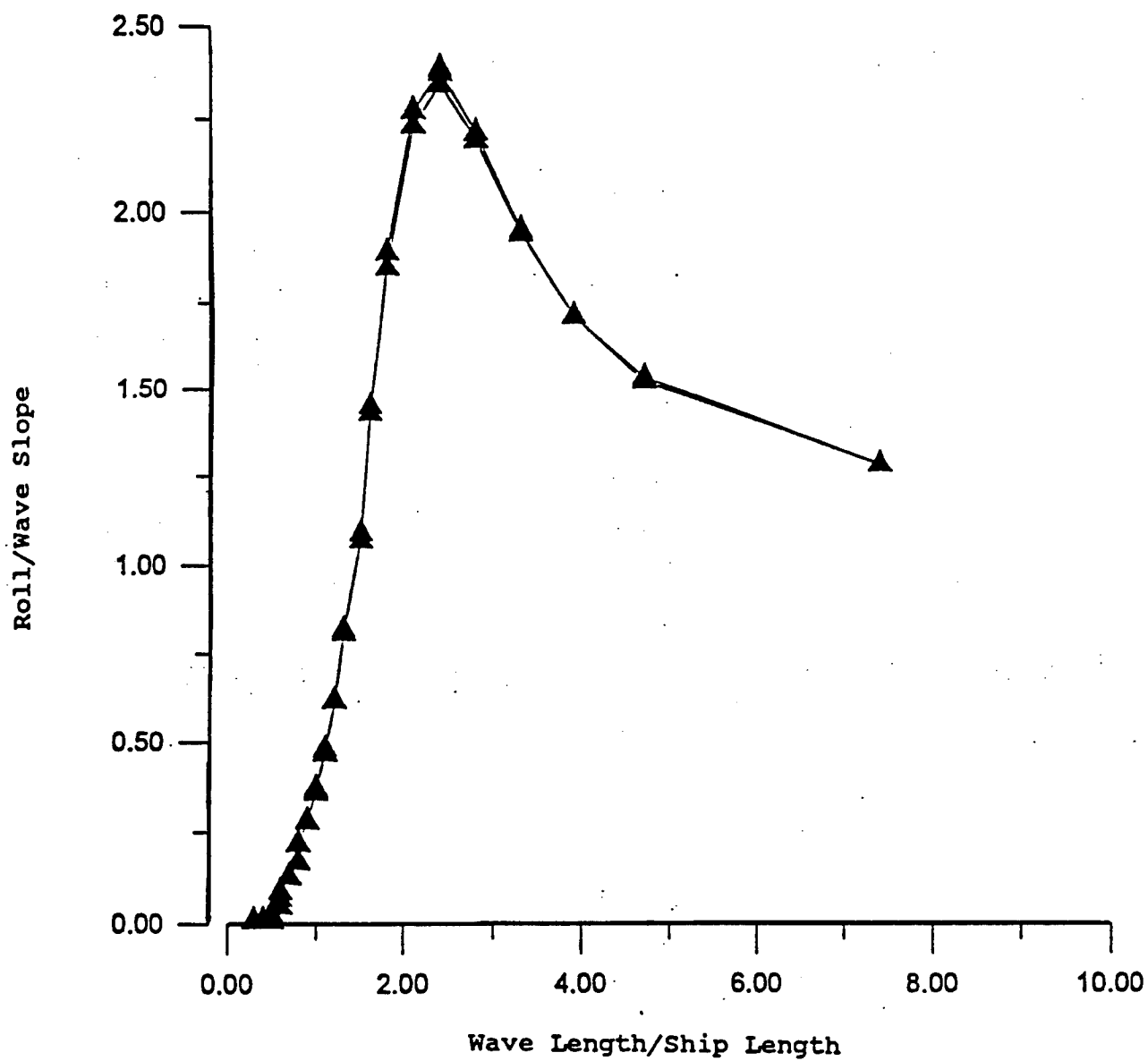
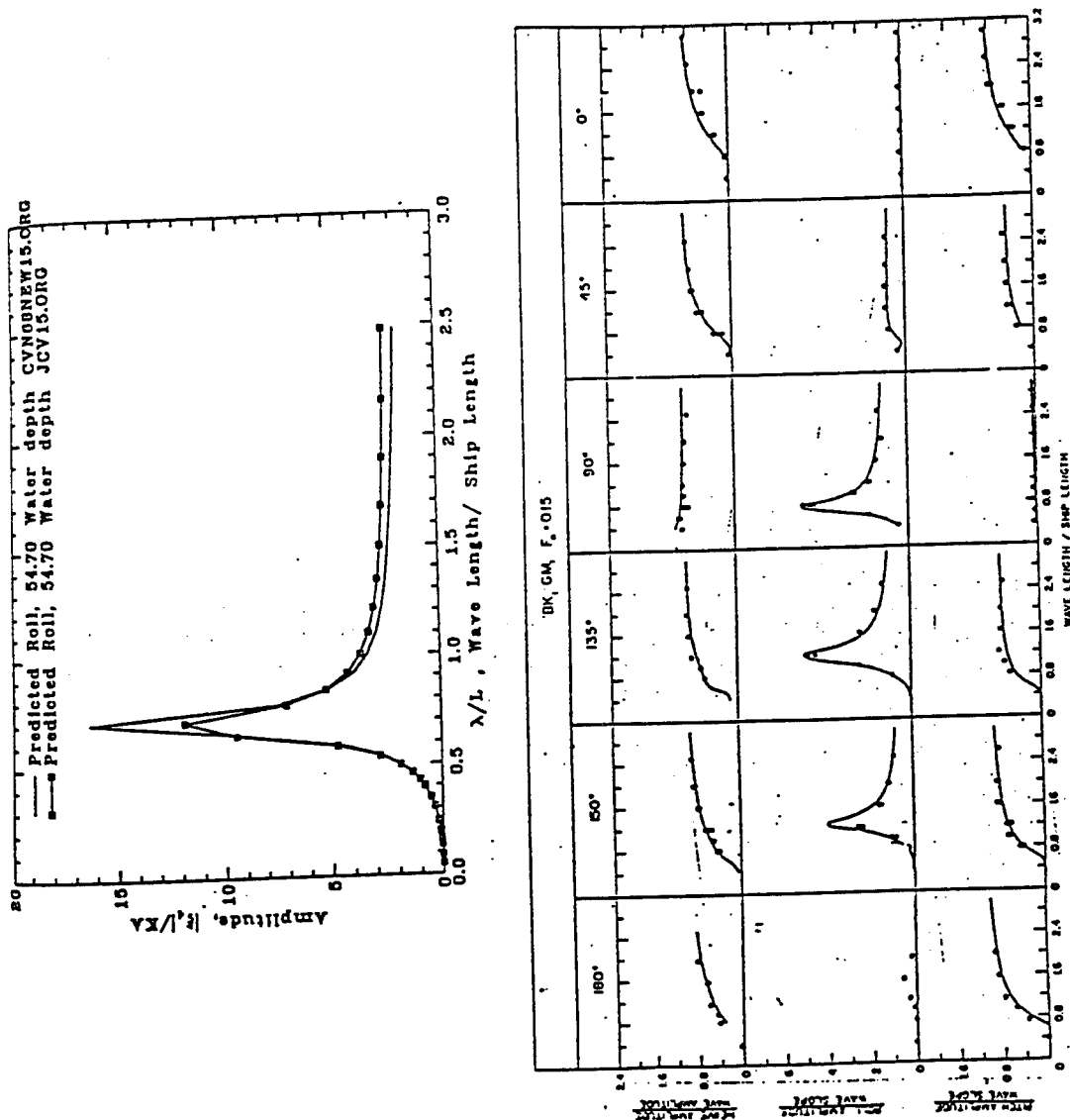
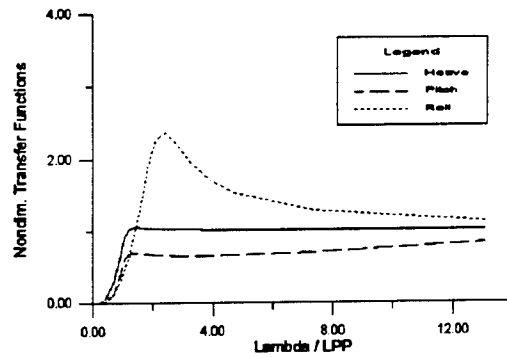


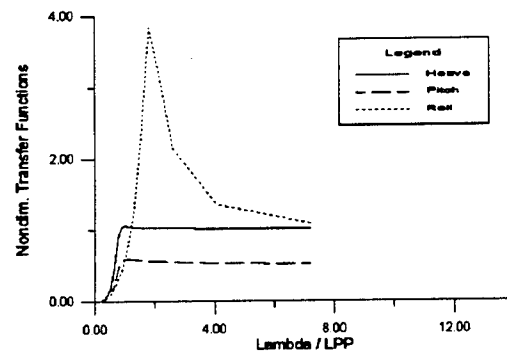
Figure C-2 Example of Non-Dimensional Roll Transfer Function for 47-Ft USCG Cutter at 5 knots in 60 Deg (Bow) Waves

Figure C-3 Examples of Non-Dimensional Transfer Functions for USN Carrier at 0 knots in Beam Seas and Destroyer Escort at $F_n=0.15$ in Head, Bow, Beam, Quartering and Following Waves

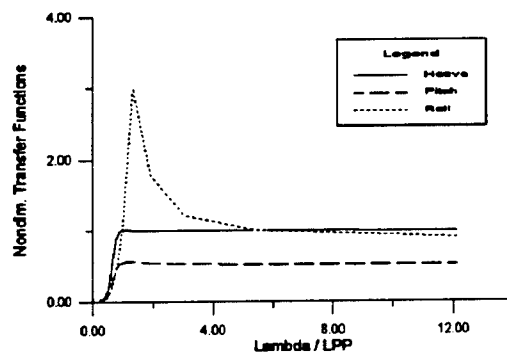




Transfer Functions for USCG 47 Ft Cutter
at 8 knots and 60 degrees Sld Bow Waves

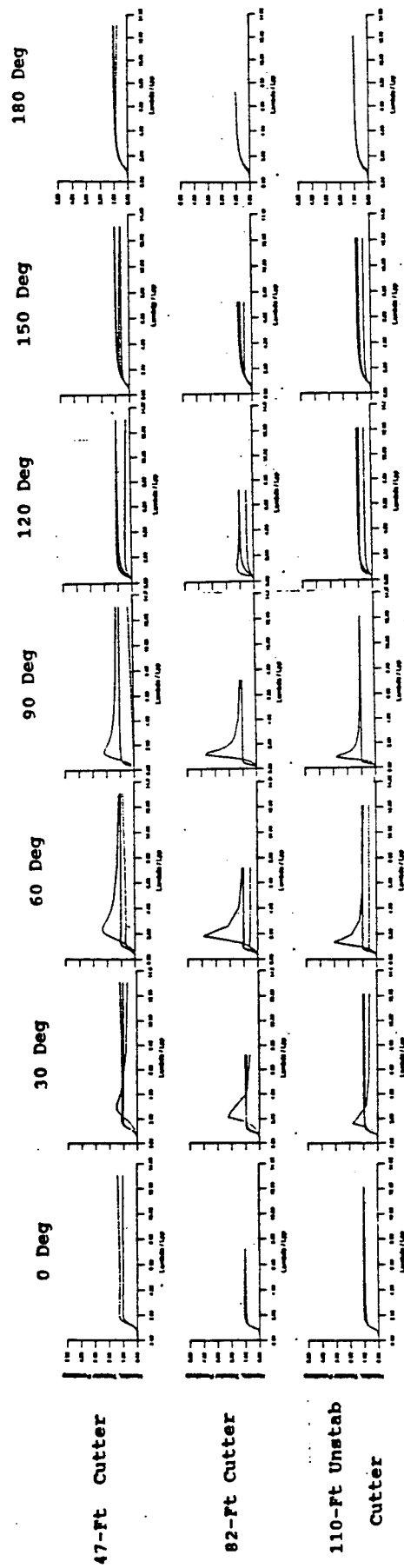


Transfer Functions for USCG 82 Ft Cutter
at 8 knots and 60 degrees Sld Bow Waves



Transfer Functions for USCG 110 Ft Cutter
at 8 knots and 60 degrees Sld Bow Waves

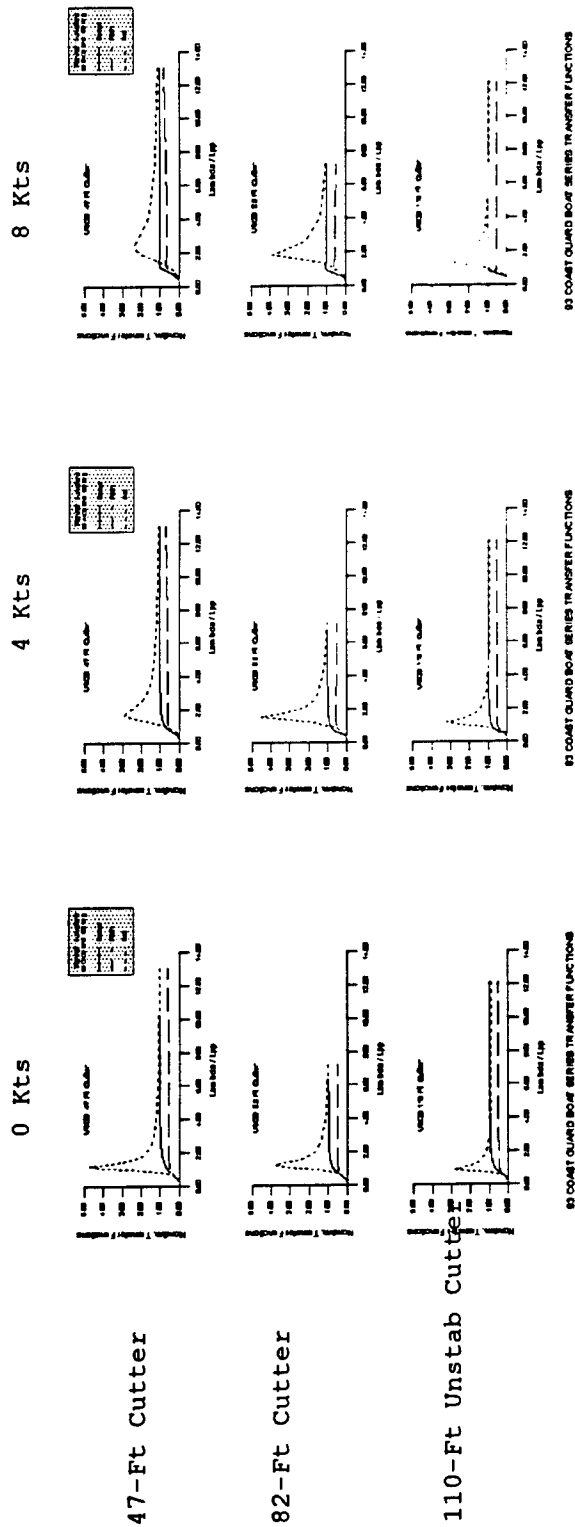
Figure C-4a Example of Non-Dimensional Transfer Functions of Heave, Roll, and Pitch for 47-Ft, 82-Ft and 110-Ft Unstabilized USCG Cutters



C-11

Figure C-4b Heading Effect at 8 knots Non-Dimensional Transfer Functions of Heave, Pitch and Roll for 47-Ft, 82-Ft and 110-Ft Unstabilized USCG Cutters

Figure C-4c Speed Effect in 60 Deg (Bow) Waves Non-Dimensional Transfer Functions of Heave, Pitch and Roll for 47-Ft, 82-Ft and 110-Ft Unstabilized USCG Cutters



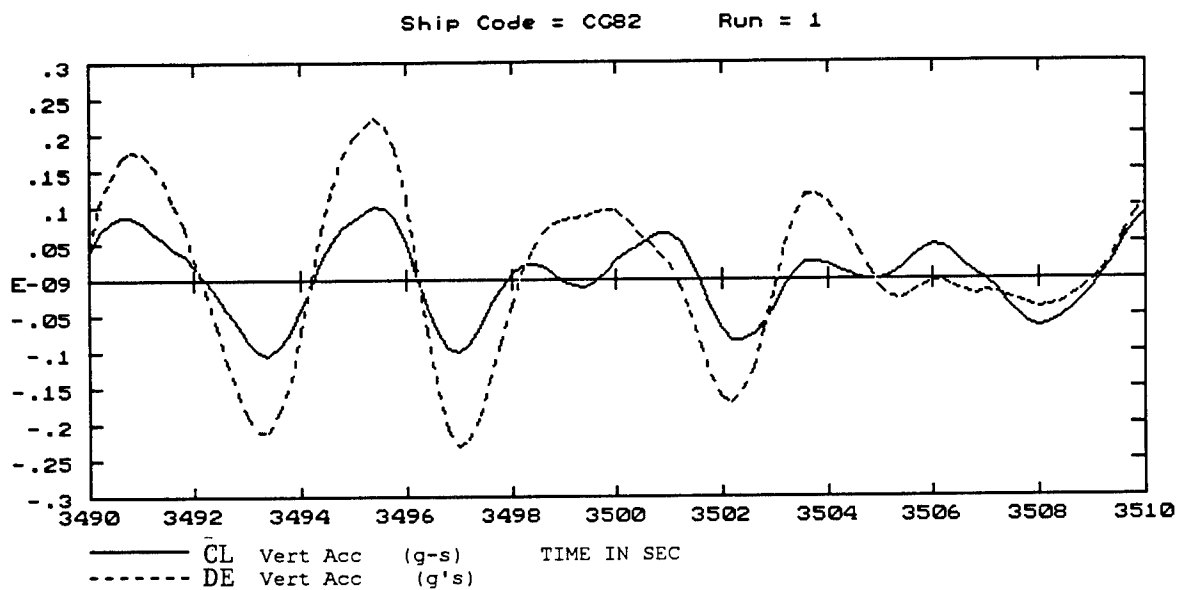


Figure C-5a Illustration of Effect of Lateral Location on Vertical Acceleration at Boat Launch Station - 82-Ft Cutter at 5 knots in 2.6 Ft, 5 Sec Modal Period Shortcrested Seas Encountered at 60 Degrees off Stbd Bow

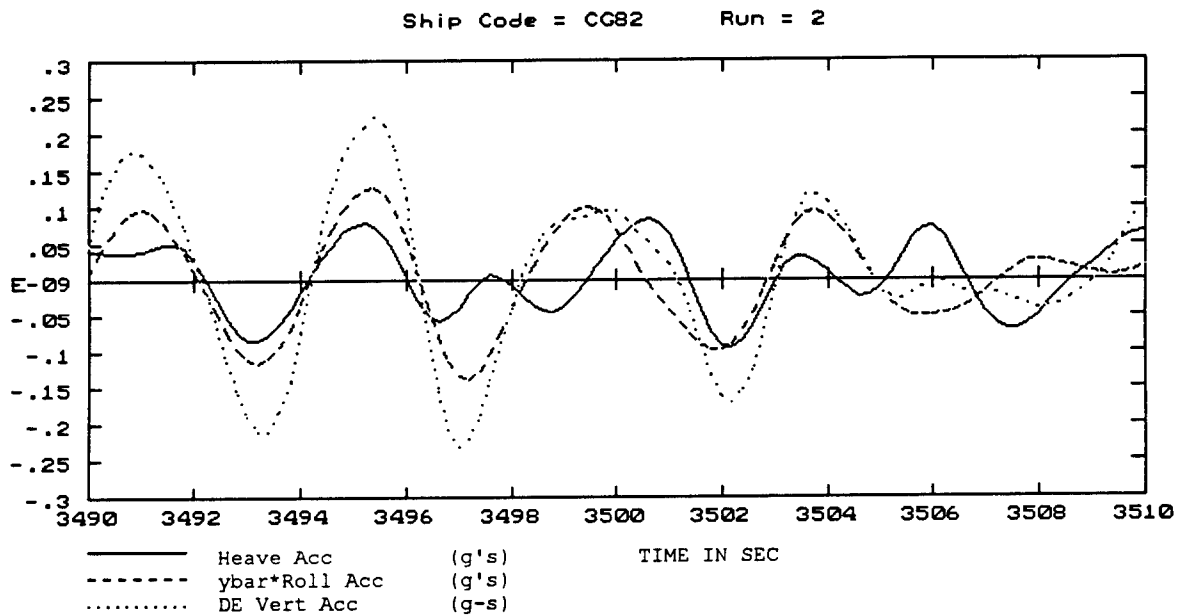


Figure C-5b Time History: Illustration of the Components of Vertical Acceleration due to Roll and Heave at the Boat Launching Location

Ship Code = CC82

Run = 1

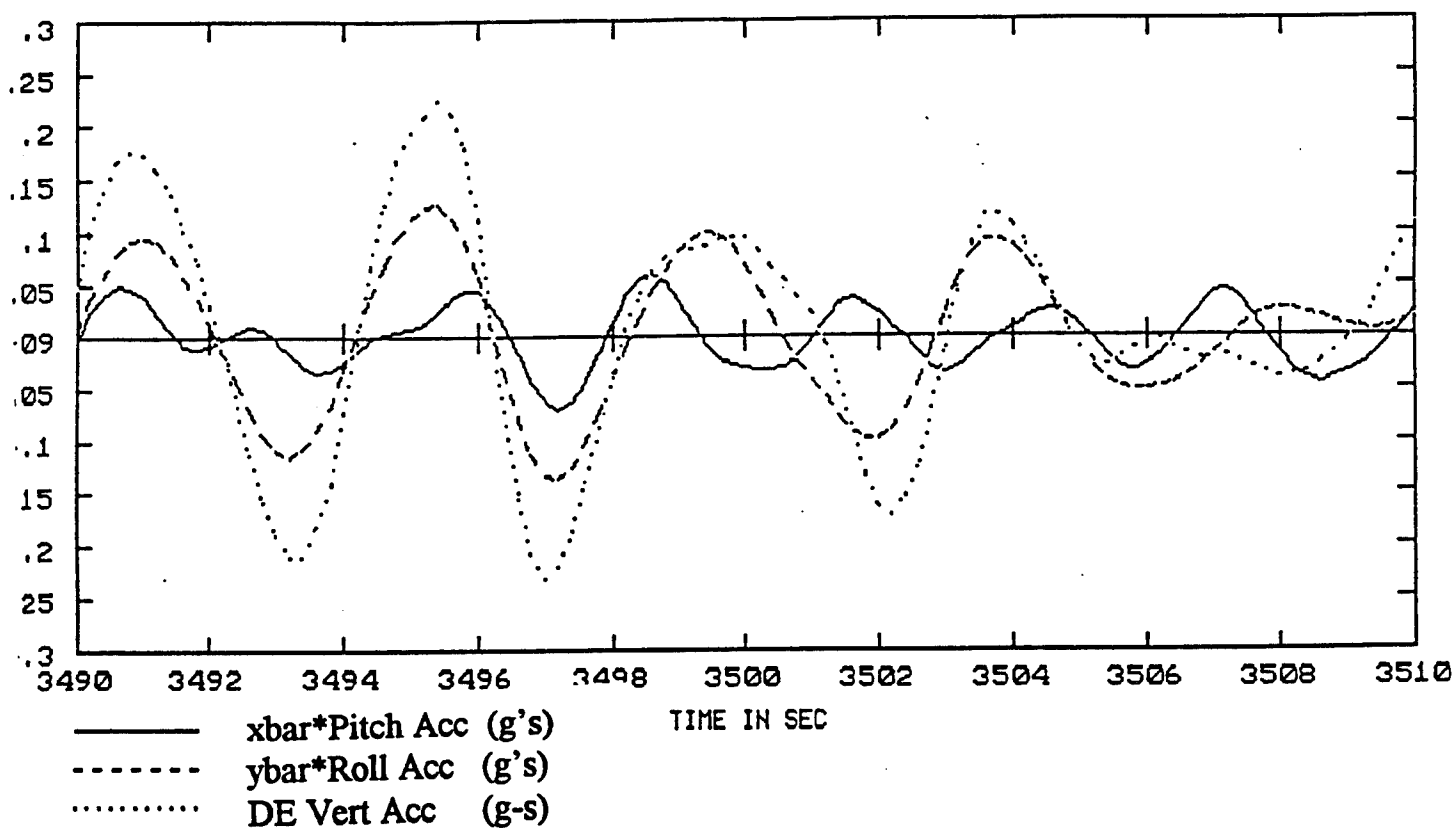


Figure C-5c Time History: Illustration of the Components of Vertical Acceleration due to Roll and Pitch at the Boat Launching Location

Ship Code = CG82 Run = 1 DTG = 021005L JUN93 Time = 0- 1800 secs
 ZERO-CROSSING PERIOD

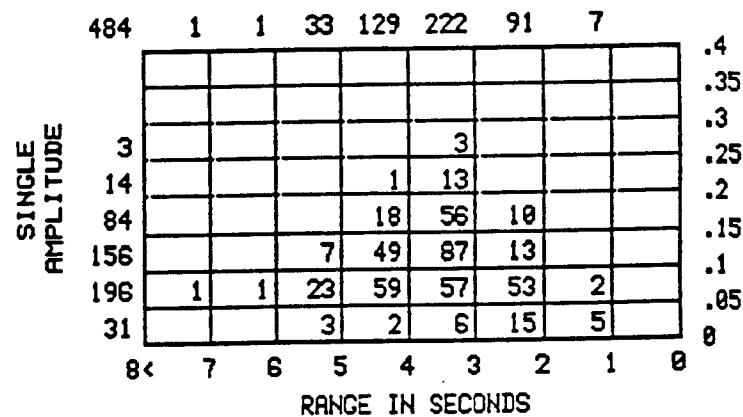
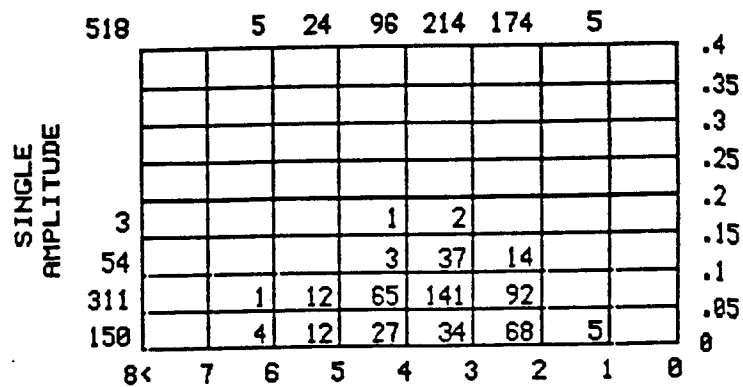
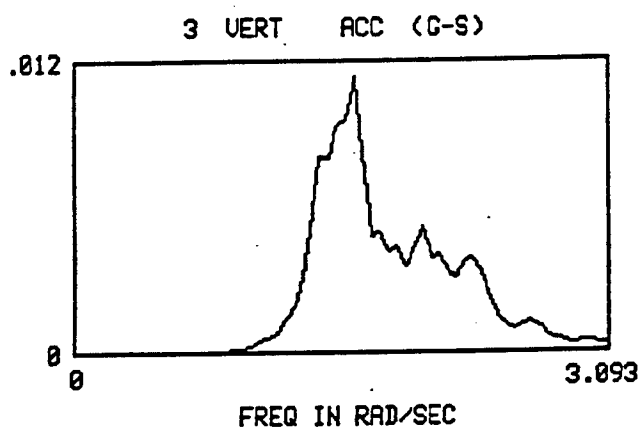
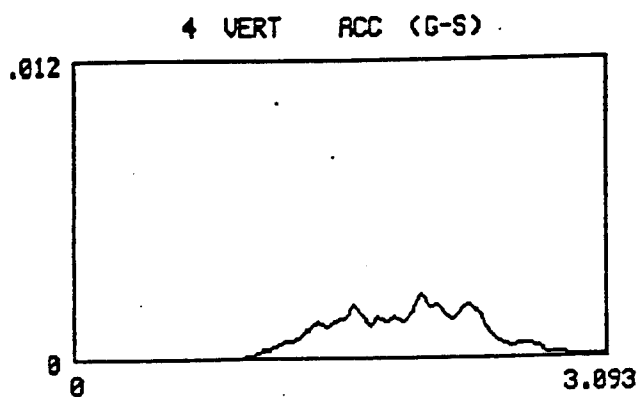


Figure C-6a Power Spectra and Single Amplitude Distributions: Illustration of Effect of Lateral Location on Vertical Acceleration at Boat Launch Station

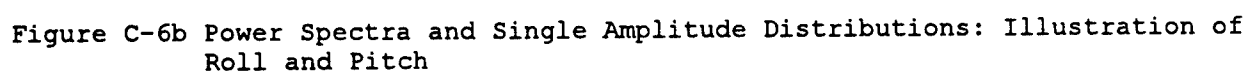
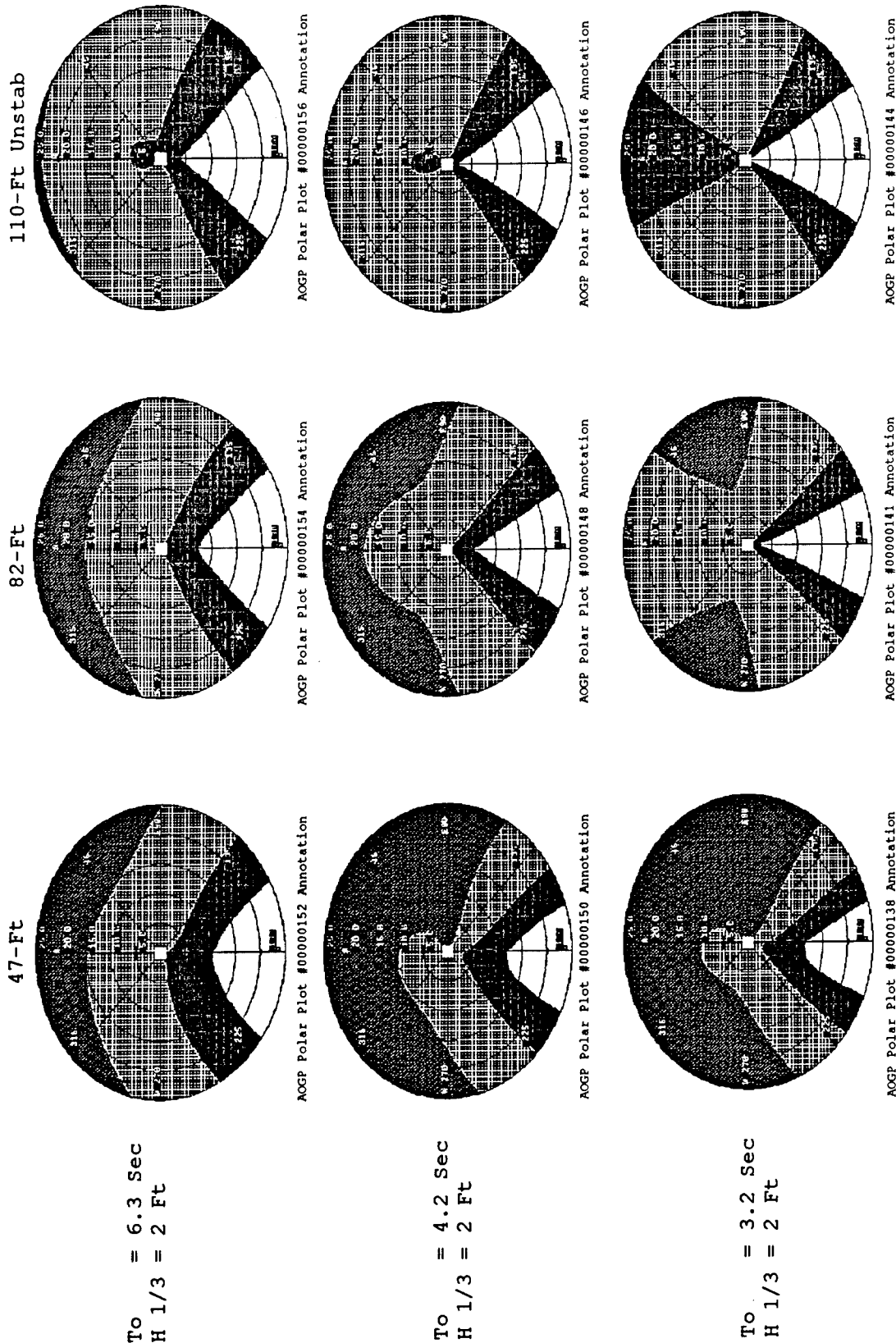
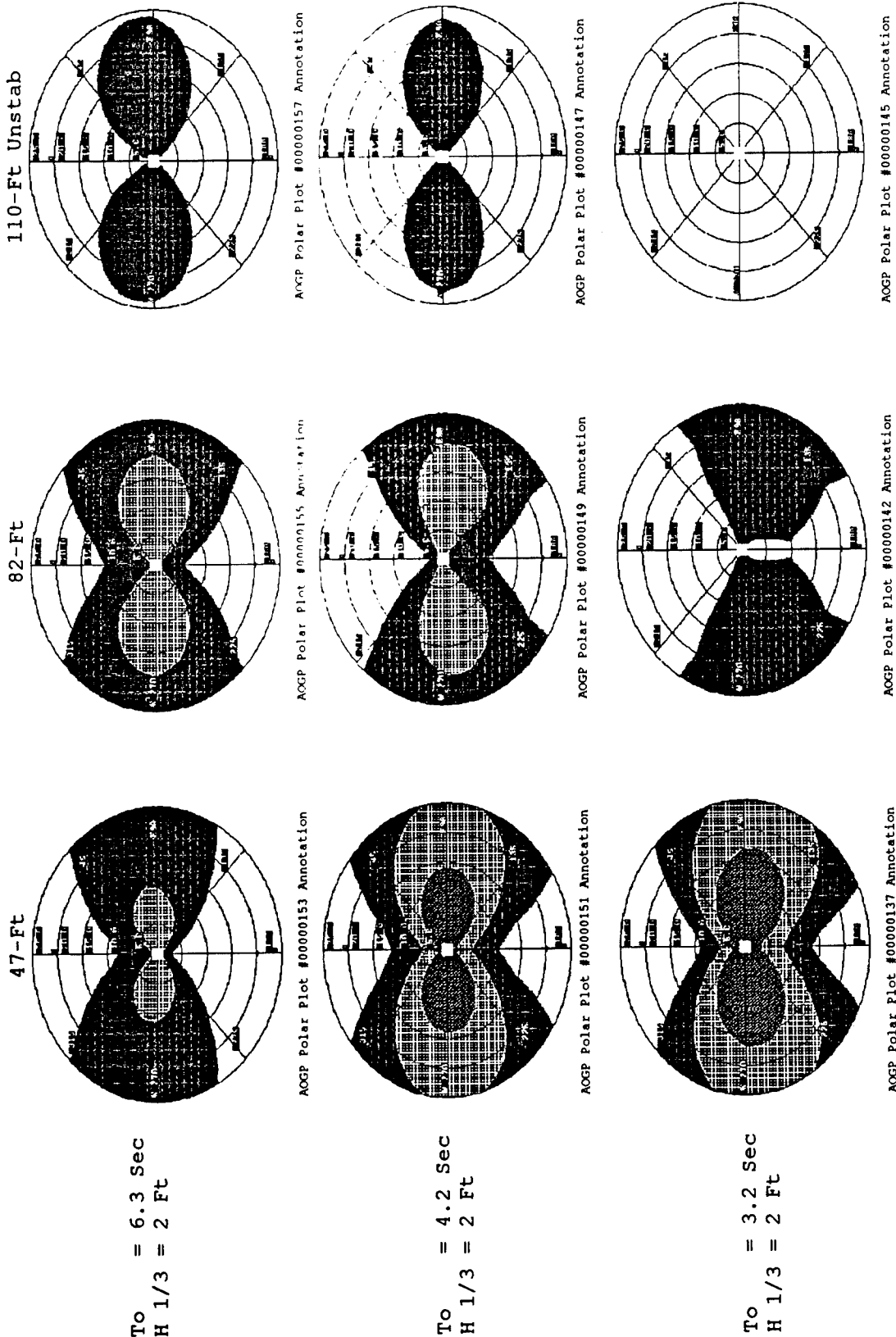


Figure C-7 Effect of Modal Wave Period in 2-Ft Significant Wave Height on Vertical Acceleration at the Pilot House for the 47-Ft, 82-Ft, 110-Ft USCG Cutters in Polar Plot Form, with speeds ranging from 0 to 10 knots in 2 knot increments



NOTE: Speed Scale of Polar Graph shown in 5 knots increments was Mislabeled, the data is for 2 knot increments!

Figure C-8 Effect of Modal Wave Period in 2-Ft Significant Wave Height on Roll Angle for the 47-Ft, 82-Ft, 110-Ft USCG Cutters in Polar Plot Form, with speeds ranging from 0 to 10 knots in 2 knot increments



NOTE: Speed Scale of Polar Graph shown in 5 knots increments was Mislabeled, the data is for 2 knot increments!

APPENDIX D

MSI - CALCULATION PROCEDURE & 1992 DATA

Ride Quality Evaluation with ISO Standards 2631

Background

The ISO Standard ISO 2631 is a set of standards and procedures for the evaluation of human exposures to whole-body vibration. The standard 2631 comprises of four parts. Part 1 states the general requirements (1 to 80 Hz); Part 2 is relevant to shock in buildings (1 to 80 Hz); Part 3 is restricted to vertical axis vibrations in the frequency range of 0.1 to 0.63 Hz; and Part 4 deals with crew exposure to vibration on board sea-going ships (1 to 80 Hz). Of these four parts, part 2 is not relevant to our study, and part 4 is at a draft stage and not yet available.

The intent of the ISO standard 2631 is to set limits for human exposure to vibrations, and is not meant to be used as a measure or predictor of motion sickness incidents. Some correlation, however, between ISO standards 2631 and "10 percent" incidents of motion sickness is implied in part 3.

Since most of the energy contents of the vertical accelerations are below 1 Hz for the boats under consideration, Part 3 of the ISO 2631 is the most relevant to the study at hand. The severe discomfort boundaries of vertical accelerations experienced by ship/boat riders are provided by Part 3 of ISO 2631. These discomfort boundaries are cited to represent a Motion Sickness Incidence of 10% for "infrequent", inexperienced travelers. Table D-1 shows the MSI calculation program source code. The tabulation of these boundaries of severe discomfort for vertical accelerations expressed in g's are in Table D-2.

MSI and Equivalent g's Variation Calculation

The actual g's used as part of Base Criteria Set = .065 g for 30 Minutes for a period of 5 seconds corresponds to a value of MSI of 5% as predicted, but this value is regarded as more likely to represent about 10% of actual crew experiencing MSI. Note in this boat study a very stringent criteria of MSI is thus imposed. This level of MSI is to correspond to no degradation in crew due to MSI. However, although this may appear to be very stringent, it should be recognized that the MSI theory does not include the MSI that will inevitably occur as the mission duration goes beyond a few minutes or a couple of hours. The MSI criteria thus DOES NOT include the MSI induced by the motion induced fatigue MIF. Table D-3 gives the % MSI to g values correspondence with RMS vertical acceleration for different Modal periods. Therefore the MSI criteria used in this boat study is very stringent to cope for the absence of the missing MIF criteria which clearly limits crew performance.

The initial SOW yielded MSI criteria levels 2 and 3 which were replaced by MSI criteria level 1 i.e.

0.	8 hr MOST Stringent 10%	i.e. .0393g	10% most restrictive
1.	30 min use MORE Stringent	i.e. .065 g	5% **base
2.	30 min use 2631 standard	i.e. .102 g	14% less restrictive
3.	240 min use 50% MSI or	.15 g	LEAST restrictive

1/3 Octave Band Procedure

One of the basic assumptions of this procedure is that there is no

significant interactions among vibration effects on humans at different frequencies. So that the effect of vibrations occurring simultaneously at various frequencies can be evaluated at each of the frequencies.

When the vibration is broad banded, the effect of the vibration is evaluated by subdividing the acceleration power spectrum into 1/3 octave frequency bands. A 1/3 octave frequency band divides the spectrum into bands where the upper frequency (f_u) of a particular band is related to the lower frequency (f_l) of that band by:

$$f_u = 2^{1/3} f_l$$

with a center frequency (f_c) associated with that band given by:

$$f_c = 2^{-1/6} f_u = 2^{1/6} f_l$$

The R.M.S. vertical accelerations within these bands are then computed and compared to the ISO standards at the associated center frequencies for evaluation.

Applications

The 1/3 octave band procedure for evaluating the effect of vertical vibrations is illustrated in the following two examples. The first example looks at the vertical accelerations induced by a Ship Motion Simulator, and the second example looks at the vertical accelerations of three boats as predicted by the Ship Motion Program. The ISO standards shown in Figures D-1 and D-2 for the frequency range below 1 Hz are the "Severe Discomfort Boundaries" (SDB) at various exposure times and are the ISO 2631/3 standards; those above 1 Hz are the "Fatigue Decreased Proficiency (FDP) Boundaries" at various exposure times and are the ISO 2631/1 standards. The R.M.S. accelerations given for the 1/3 octave band procedure in the figures are the 1/3 octave band accelerations with center frequencies as indicated. The R.M.S. accelerations given for the Carderock procedure are the total accelerations placed at the peak encounter frequencies (1/TOE).

Ship Motion Simulator Experiments

The results of the experiments are shown in Figures D-3 through D-6 for various runs. Both the 1/3 octave band procedure and the Carderock procedure results are plotted. The first figure shows that for the two runs indicated, the 1/3 octave band procedure states that the vibration levels are acceptable for exposures up to approximately 4 hours. The actual experiment has shown that from 15 to 30 percent of the subjects became ill after only one hour of exposure. The Carderock procedure gives somewhat better prediction, but still under predicts the severity of the vibration effects. The second figure replots the first figure to show only the ISO/SDB frequency range. The third and fourth figures summarize the results for all runs, and as can be seen, all the vertical accelerations are at similar levels and frequency ranges.

SMP Predictions

In order to evaluate the ride qualities of CG 110, CG 82, and CG 47 boats, the vertical accelerations at three points on the boats were

computed using Ship Motion Program (SMP). Table D-4 shows the point locations for 1993 USCG seakeeping criteria boat series. The actual program used is a modification of SMP93 that generates 1/3 octave frequency band r.m.s. accelerations for use with ISO 2631 standards.

The program was run for three sets of speeds - 5 knots, economical cruising speeds (CG 110 @ 10 kts, CG 82 @ 8 kts, and CG 47 @ 8.5 kts), and maximum sustained speeds (CG 110 @ 25 kts, CG 82 @ 18.5 kts, CG 47 @ 22 kts). All runs were made using a Bretchneider wave spectrum with significant wave height of 2.62 feet and modal periods ranging from 5 to 17 seconds. All headings from head to following seas in increments of fifteen degrees for both the port and the starboard sides were considered (000-Head, 180-Following). At each speed for each boat, the condition at which a maximum vertical acceleration (1/3 octave band acceleration for ISO procedure, and total acceleration for Carderock procedure) was observed was selected and the results are shown in the r.m.s. acceleration plots below.

At 5 knots, 1/3 octave band procedure indicates that CG 47 can be operated for up to 2 hours before exceeding the ISO standard, CG 110 little over one hour, and CG 82 little less than one hour.

At economical cruising speeds, 1/3 octave band procedure indicates the CG 47 can be operated for up to 2 hours, CG 110 up to 45 minutes, and CG 82 up to 45 minutes.

At maximum cruising speeds, 1/3 octave band procedure indicates the CG 110 and CG 82 should be operated for less than 30 minutes. The results for CG 47 is inconclusive due to lack of data high frequencies.

THE MAXIMUM VERTICAL ACCELERATION CONDITIONS

At 5 knots:

	CG 110	CG 47	CG 82
Point Location #	2	3	2
Modal Period (sec)	5	5	5
Heading (degrees)	015	060 (045)*	015

At economical cruising speeds:

	CG 110	CG 47	CG 82
Point Location #	2	3	2
Modal Period (sec)	5	5	5
Heading (degrees)	000	015 (030)	000

At maximum cruising speeds:

	CG 110	CG 47	CG 82
Point Location #	2	3	2
Modal Period (sec)	7	5	5
Heading (degrees)	000 (345)	000	000

* Values inside the parenthesis indicate those for Carderock procedure when they are different from 1/3 octave band procedure.

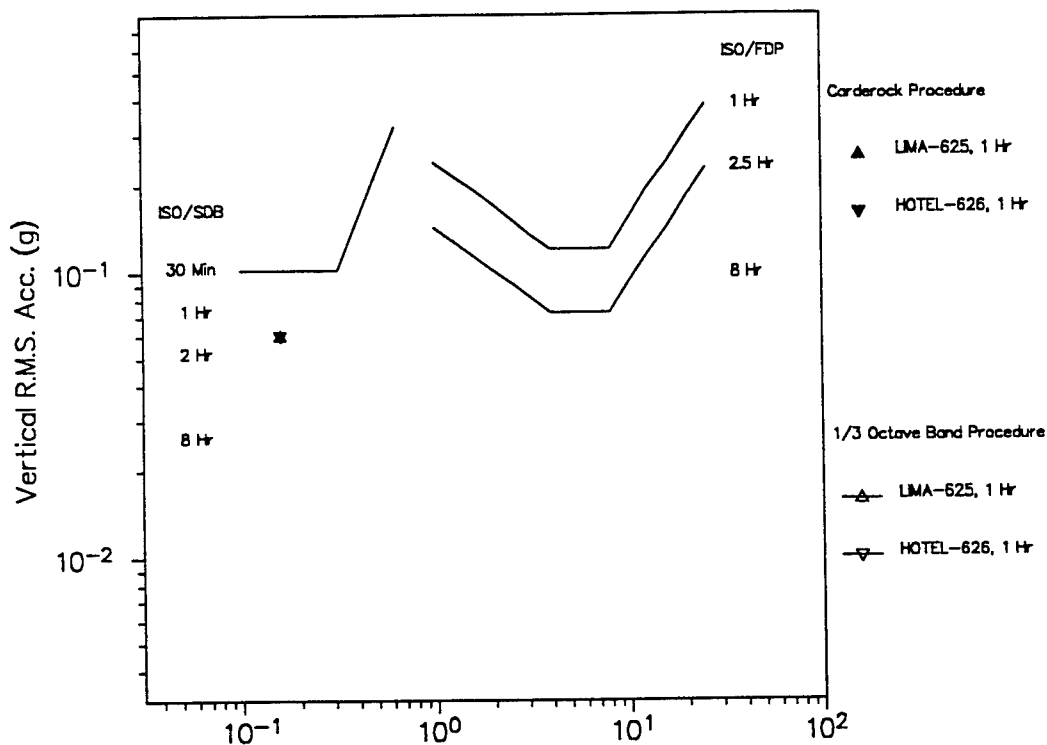


Figure D-1 Combined Results - Severe Discomfort Boundaries of Vertical Accelerations (~ 10% MSI) From ISO 2631-3 and Fatigued Decreased Proficiency (FDP) Boundaries 2631-1 including 1992 NBDL MII Experiment Motion Simulator Vertical Accelerations for LIMA and HOTEL Test Conditions

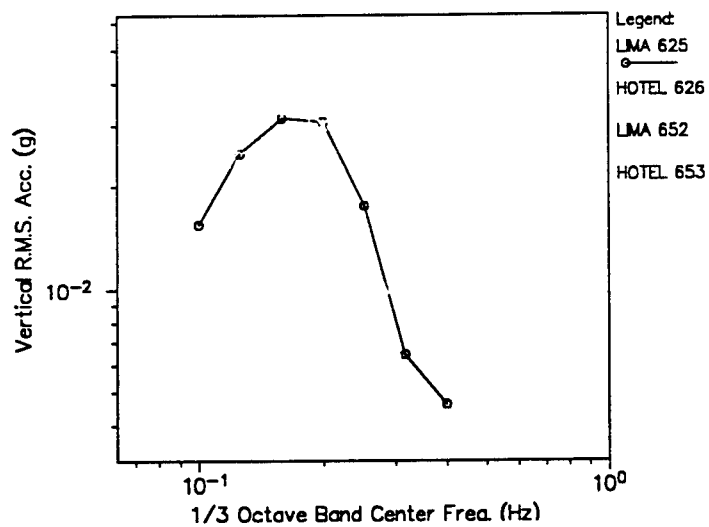
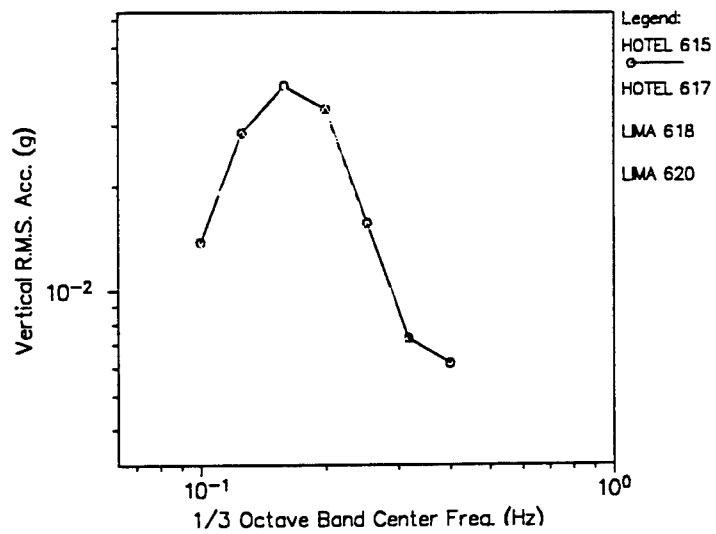


Figure D-2 Summary of 1992 NBDL MII Experiment Motion Simulator Vertical Accelerations for first and last runs in Main Study LIMA and HOTEL Test Conditions - 1/3 Octave Band Presentation Format

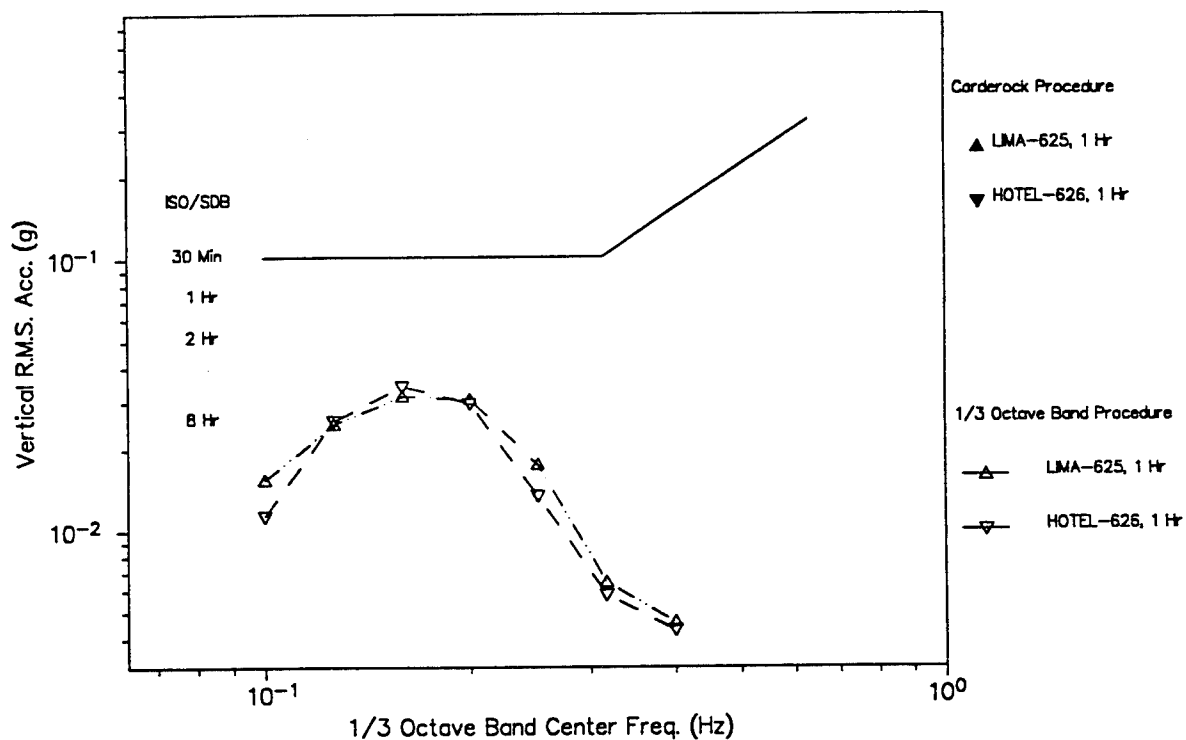


Figure D-3 Comparison of 1/3 Octave Band RMS Vertical Acceleration Calculation Procedure and Carderock Total RMS Vertical Acceleration Calculation Procedure with ISO 2631-3 Severe Discomfort Boundaries (or Approximate 10% MSI Occurrence) for Measured Vertical Accelerations from 1992 MII Experiments in NBDL Motion Simulator

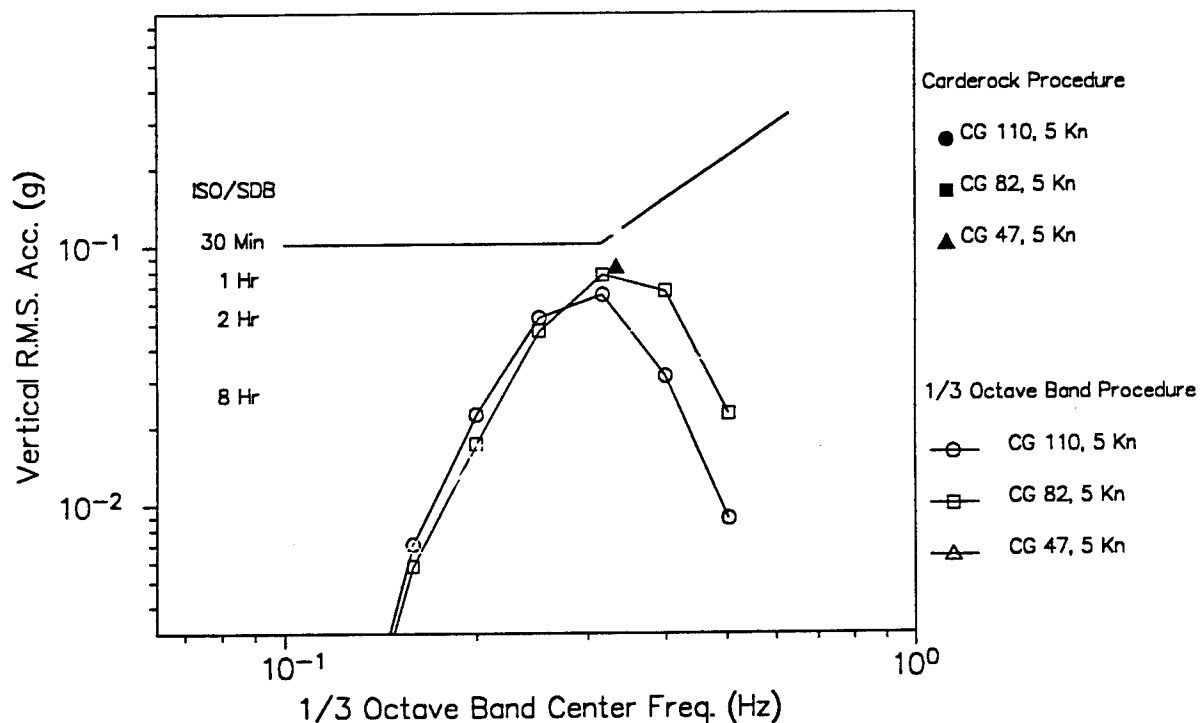


Figure D-4 Comparison of 1/3 Octave Band RMS Vertical Acceleration Calculation Procedure and Carderock Total RMS Vertical Acceleration Calculation Procedure with ISO 2631-3 Severe Discomfort Boundaries (or Approximate 10% MSI Occurrence) for Predicted "Worst" Accelerations at Crew Rest Location in USCG 1993 Boat Series at 5 knots (Low Speed Operating Conditions)

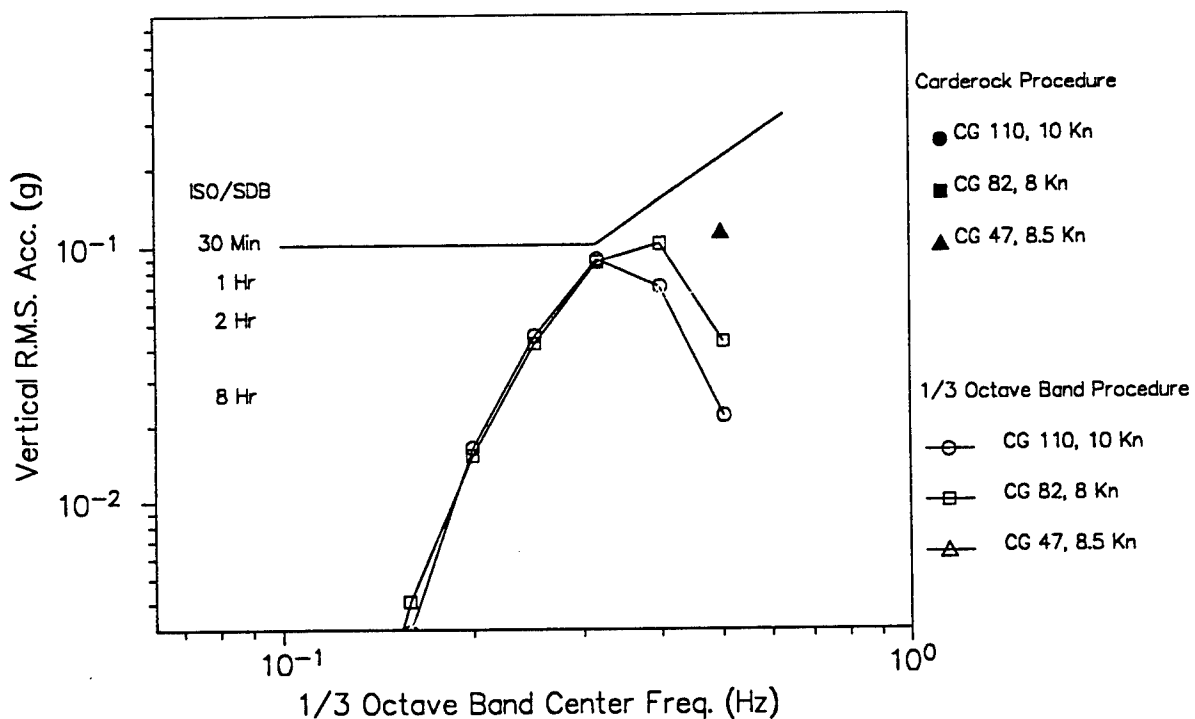


Figure D-5 Comparison of 1/3 Octave Band RMS Vertical Acceleration Calculation Procedure and Carderock Total RMS Vertical Acceleration Calculation Procedure with ISO 2631-3 Severe Discomfort Boundaries (or Approximate 10% MSI Occurrence) for Predicted "Worst" Accelerations at Crew Rest Location in USCG 1993 Boat Series at 8-10 knots (Economical Cruising Speed Operating Conditions)

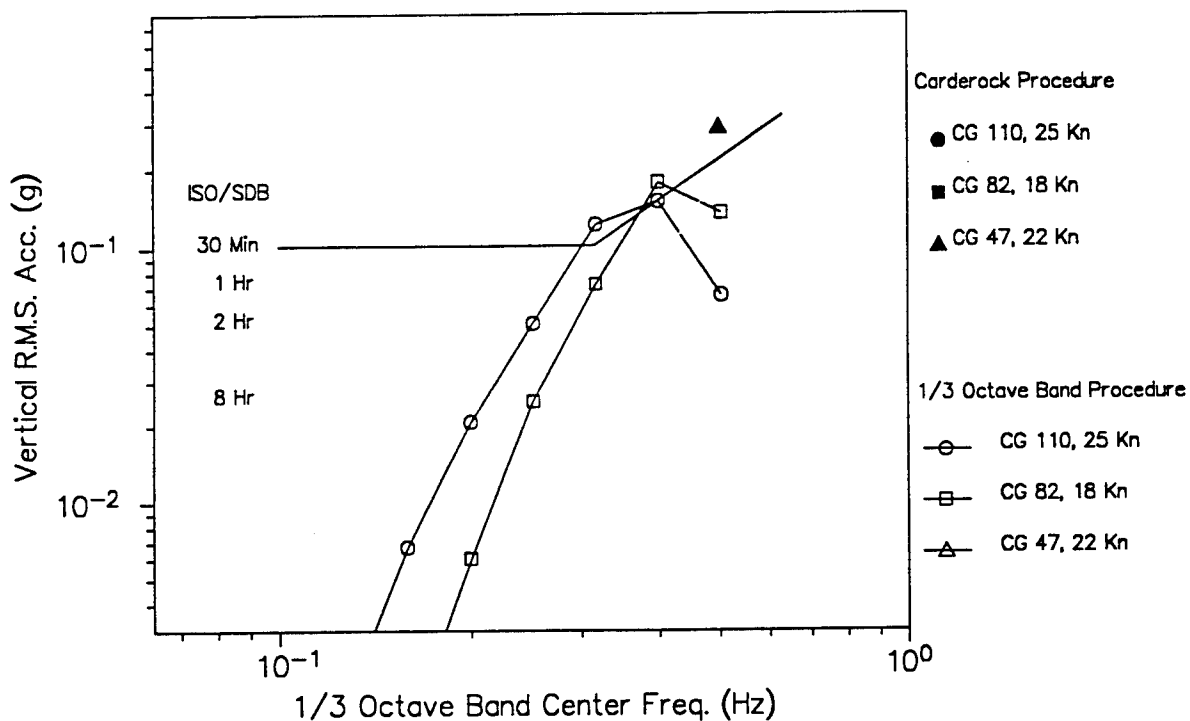


Figure D-6 Comparison of 1/3 Octave Band RMS Vertical Acceleration Calculation Procedure and Carderock Total RMS Vertical Acceleration Calculation Procedure with ISO 2631-3 Severe Discomfort Boundaries (or Approximate 10% MSI Occurrence) for Predicted "Worst" Accelerations at Crew Rest Location in USCG 1993 Boat Series at 18-25 knots (Maximum Sustained Cruising Speed Operating Conditions)

Table D-1 MSI Calculation Program, Source Code

```

PROGRAM MSIMAIN

REAL MSIVAL

*   VARMS = 0.102      ! g's
*   VATOE = 5.0        ! seconds
*   TIME = 30          ! minutes

WRITE (*,*) 'Enter vertical acc RMS and Toe values ? '
READ (*,*) VARMS,VATOE

WRITE (*,*) 'Enter time duration in minutes ? '
READ (*,*) TIME

CALL MSI (VARMS,VATOE,MSIVAL,TIME)
WRITE (*,1000) VARMS,VATOE,MSIVAL,TIME
1000 FORMAT (/ ' VARMS = ',F5.3,' gs'
2         / ' VATOE = ',F5.1,' sec'
2         / ' MSI   = ',F5.1,' %'
2         / ' Time duration = ',F7.1,' min')

STOP
END

C DECK MSI

SUBROUTINE MSI (VARMS,VATOE,MSIVAL,TIME)

*   This subroutine calculates motion sickness incidence
*   developed by HUMAN FACTORS RESEARCH, INC., in
*   "MOTION SICKNESS INCIDENCE" exploratory studies of
*   habituation, pitch and roll and the refinement of a
*   mathematical model," by M.E. MCCAULEY, et al., Apr. 1976.
*   The variables used are RMS vertical accelerations for
*   significant wave heights and encounter modal frequencies.
*   The subroutine uses function STDPHI.

REAL MSIVAL

FREQ = 1. / VATOE
FLOG = ALOG10(FREQ)
AMU = 0.87 + FLOG * (4.36 + (2.73*FLOG))
ZA = (ALOG10(VARMS) - AMU) / 0.47

*   Time duration equals 120 minutes

ZTP = (ALOG10(TIME) - 1.46 + 0.57 * ZA) / 0.5027
MSIVAL = 100. * STDPHI (ZA) * STDPHI (ZTP)

RETURN
END

C DECK STDPHI

FUNCTION STDPHI (Z)

*   This function is an approximation method used by subroutine MSI
*   to estimate the value of the standardized cumulative normal
*   distribution function PHI

AZ = ABS(Z)
W = 1.0/(1.0 + 0.2316419 * AZ)
ARG = Z*Z / 2
IF (ARG .GT. 500.) D = 0.
IF (ARG .LE. 500.) D = 0.3989423 * EXP(-ARG)
X = (((((1.330274*W-1.821256)*W+1.781478)*W-0.3565638
2  *W+0.3193814)*W
STDPHI = 1.0 - D * X
IF (Z) 1,2,2
1  STDPHI = 1.0 - STDPHI
2  RETURN
END)

```

Table D-2 Severe Discomfort Boundaries - Vertical Accelerations

fu, Hz	Freq, fc, Hz (Center Freq of one-third octave band)	fl, Hz	Vertical Acc, g's Exposure Time, Hrs			Period, Sec (Center of one-third octave band)
			.5	2	8	
0.112	0.10	0.56	0.10	0.05	0.03	10.00
0.141	0.13	0.71	0.10	0.05	0.03	8.00
0.178	0.16	0.89	0.10	0.05	0.03	6.30
0.224	0.20	1.12	0.10	0.05	0.03	5.00
0.283	0.25	1.41	0.10	0.05	0.03	4.00
0.356	0.32	1.78	0.10	0.05	0.03	3.15
0.449	0.40	2.24	0.15	0.08	0.04	2.50
0.566	0.50	2.82	0.22	0.11	0.06	2.00
	0.63		0.32	0.16	0.08	1.59

Table D-3 - MSI Criteria Selection: % MSI to g Value Correspondence with RMS Vertical Accelerations For To Periods 3.15, 4.0, 5.0, 6.3, 8.0 and 10 seconds

Vertical Acc = 3.15 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	11.0	18.8	26.0	30.6	32.7	
0.15 =	10.2	17.7	24.8	29.4	31.5	
0.10 =	4.3	8.7	13.8	18.0	20.4	
0.10 =	4.1	8.3	13.3	17.5	19.9	
0.09 =	2.7	5.9	10.0	13.7	16.1	
0.07 =	1.1	2.7	5.2	7.9	9.9	
0.06 =	0.8	2.1	4.3	6.6	8.6	
0.05 =	0.4	1.3	2.7	4.6	6.2	
0.04 =	0.2	0.5	1.2	2.3	3.4	
0.03 =	0.1	0.2	0.6	1.3	2.0	
0.03 =	0.0	0.1	0.4	0.8	1.4	
0.03 =	0.0	0.1	0.2	0.6	1.0	

Vertical Acc = 6.3 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	30.1	41.7	52.6	52.6	53.7	
0.15 =	28.7	40.1	47.7	51.2	52.4	
0.10 =	15.9	25.3	33	37.4	39.2	
0.10 =	15.3	24.5	32.2	36.6	38.5	
0.09 =	11.4	19.4	26.6	31.2	33.3	
0.07 =	5.8	11.2	17.0	21.5	23.9	
0.06 =	4.7	9.4	14.8	19.1	21.5	
0.05 =	3.0	6.5	10.8	14.6	17.0	
0.04 =	1.3	3.3	6.1	9.0	11.1	
0.03 =	0.7	1.8	3.5	5.8	7.6	
0.03 =	0.4	1.1	2.5	4.2	5.7	
0.03 =	0.3	0.8	1.6	3.2	4.5	

Vertical Acc = 4 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	20.6	31.0	38.8	43.0	44.6	
0.15 =	19.4	29.6	37.4	41.7	43.3	
0.10 =	9.6	16.9	23.8	28.4	30.6	
0.10 =	9.2	16.3	23.1	27.7	29.9	
0.09 =	6.5	12.3	18.4	22.9	25.2	
0.07 =	3.0	6.5	10.8	14.6	17.0	
0.06 =	2.4	5.3	9.1	12.7	15.0	
0.05 =	1.4	3.4	6.3	9.3	11.5	
0.04 =	0.6	1.6	3.3	5.3	7.0	
0.03 =	0.3	0.8	1.8	3.2	4.5	
0.03 =	0.1	0.5	1.2	2.2	3.3	
0.03 =	0.1	0.3	0.8	1.6	2.5	

Vertical Acc = 8 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	27.3	38.6	46.2	49.9	51.1	
0.15 =	25.9	37.1	44.8	48.5	49.8	
0.10 =	13.9	22.7	30.2	34.8	36.7	
0.10 =	13.4	22.0	29.5	34.0	36.0	
0.09 =	9.8	17.2	24.1	28.8	30.9	
0.07 =	4.9	9.7	15.1	19.4	21.8	
0.06 =	3.9	8.1	13.0	17.1	19.5	
0.05 =	2.5	5.5	9.4	13.0	15.3	
0.04 =	1.1	2.7	5.1	7.8	9.8	
0.03 =	0.5	1.4	3.0	4.9	6.6	
0.03 =	0.3	0.9	2.0	3.5	4.9	
0.03 =	0.2	0.6	1.4	2.6	3.8	

Vertical Acc = 5 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	27.5	38.9	46.5	50.1	51.3	
0.15 =	26.1	37.4	45.1	48.8	50.1	
0.10 =	14.1	22.9	30.5	35.0	37.0	
0.10 =	13.5	22.2	29.7	34.3	36.2	
0.09 =	10.0	17.4	24.4	29.0	31.2	
0.07 =	5.0	9.8	15.3	19.6	22.0	
0.06 =	4.0	8.2	13.2	17.3	19.7	
0.05 =	2.5	5.5	9.5	13.1	15.5	
0.04 =	1.1	2.7	5.2	7.9	10.0	
0.03 =	0.5	1.4	3.0	5.0	6.7	
0.03 =	0.3	0.9	2.1	3.6	5.0	
0.03 =	0.2	0.6	1.5	2.7	3.9	

Vertical Acc = 10 sec period						
EXPOSURE TIME:	30 min	60 min	120 min	240 min	480 min	
g	% MSI	% MSI	% MSI	% MSI	% MSI	
0.15 =	20.2	30.5	38.3	42.5	44.1	
0.15 =	19.0	29.1	36.9	41.2	42.8	
0.10 =	9.3	16.5	23.3	28.0	30.2	
0.10 =	8.9	15.9	22.6	27.3	29.5	
0.09 =	6.3	12.0	18.0	22.5	24.8	
0.07 =	2.9	6.3	10.5	14.3	16.7	
0.06 =	2.3	5.1	8.9	12.4	14.8	
0.05 =	1.4	3.3	6.2	9.1	11.2	
0.04 =	0.5	1.5	3.2	5.2	6.9	
0.03 =	0.2	0.7	1.7	3.1	4.4	
0.03 =	0.1	0.5	1.1	2.1	3.2	
0.03 =	0.1	0.3	0.8	1.5	2.4	

Table D-4 Point Locations for 1993 USCG Seakeeping Criteria Boat Series

POINT LOCATIONS

(as given by: station number, distance off centerline (positive to port), distance above the baseline)

ABSOLUTE MOTIONS

	CG 110	CG 82	CG 47
Point Location 1	Pilot House forward of chart table (8.65, 2', 26')	Pilot House at Helmsman Chair (8.21, 0', 20')	Closed Bridge, Helmsman Chair (11.18, -1.5', 10')
Point Location 2	Forward Berthing, Port/Top Bunk (3.08, 5', 12')	Forward Berthing, Port/Top Bunk (3.33, 5', 12')	Survivor's Chamber, Port Bench (13.98, 2.5', 6')
Point Location 3	Main Deck, Aft of Boat Davit, Stbd Rail (15.96, -8.5', 13')	Main Deck, Boat Deck, Stbd Rail (15.38, -7.5', 10.5')	Open Bridge, Helmsman Chair (11.18, -2.5', 14.5')

RELATIVE MOTIONS

Point Location 1	Port Propeller Tip, Emergence (19.08, 3.75', 3.71')	Port Propeller Tip, Emergence (18.90, 4.16', 3.75')	Port Propeller Tip, Emergence (18.40, 2.97', 0.57')
Point Location 2	Station 2, Bottom Slamming (2, 0', 1.7')	Station 2, Bottom Slamming (2, 0', 2')	Station 2, Bottom Slamming (2, 0', 0.66')
Point Location 3	Main Deck, Aft of Boat Davit, Stbd Rail, Wetness (15.96, -8.5', 13')	Main Deck Boat Davit, Stbd Rail Wetness (15.38, -7.5', 10.5')	Open Bridge, Helmsman Chair, Wetness (11.18, -2.5', 15.4')

APPENDIX E

SEP PROGRAM DEVELOPMENT AND MODIFICATIONS

During 1987 - 1989 when the mainframe computer at Carderock was once again being changed, it was decided to move SEP from the mainframe to the PC. This was accomplished by DTRC Code 1561 under sponsorship of the US Navy Seaway Improvement Program, SPIP. The resultant PC based version of SEP was compared to the operating version of SEP in use by the NAVSEA ship design code, Code 55W3 that had been transferred to a VAX minicomputer. The changes in the PC version from the initially documented VAX version

(Document: Report - DTNSRDC/SPD-1223-01 Mar 1987: Seakeeping Evaluation Program(SEP): User's Manual by Kathryn K. McCreight & Ralph G. Stahl)

included:

1. Jun `87 Transfer Limited Pacific Wave Data Base to PC
2. Jul `87 Transfer North Atlantic Wave Data Base to PC including source code for SEP
3. Aug 87 Convert SEP from `87 VAX version into `87 PC Version
4. Jun '88 Add Pacific Wind to Data Base
5. Jul `88 Incorporate UNRESTRICTIVE Ops into SEP
6. Jul `88 Add Addition Pacific Wind / Wave Data Base Points
7. Aug `88 Add Indian Ocean etc Wind/Wave Data Base
8. Dec `88 Add Graphic Output for PTO Versus Geography
9. Nov '91 - Nov `92 Incorporate MII (Slide/Tip) to SEP
10. Nov `91 - Nov `92 Alter Wave Data base format from sequential ascii to random access binary file
11. Jan `93 Add 10 Point USCG 93 Boat Series Wave Data Base
12. May `93 Add MSI capability to SEP-93
13. Jun `93 Alter SEP-93 Wave Periods/10 Point USCG 93 Boat Wave data base

SEP Wave Periods

All of the SEP output files through early June 11, 1993 were calculated using the initial SOWM model wave period set. This fifteen (15) wave period set was contained in the CG wave data base constructed for this 1993 Boat Seakeeping Criteria study in December 1992 and January 1993. The values of wave periods in the SOWM model are not equally spaced (in seconds). More resolution is provided in the original SOWM model wave set for longer wave periods than for intermediate and shorter wave periods in order to adequately represent the swell that persists most

of the time in the open ocean.

Based on a detailed analysis of the basic ship motion response characteristics of the boats during the second week of June 1993, this initial set of SOWM model wave periods was found to be inadequate for the definition of the frequency of occurrence of significant responses of the vessels.

The ship motion response trends for the four boats were examined as to determine why the 47-Ft cutter performed better relative to the larger cutters. During this search, it was recognized that this SOWM models wave periods contained only TWO wave periods in the range of the natural periods (3.1 to 4.8 seconds) of the three boats. It was considered that this would not adequately represent the waves which would excite the majority of the boats responses.

Accordingly during the am of 11 June 1993, a meeting was held to rearrange the wave input data base to more accurately reflect the probable distribution of wave periods as the input to the SEP ship performance model. Thus, during this late stage in the analysis of the 1993 USCG boat series, the adequacy of the basic wave data base for describing the wave environment in which the boats nominally operate had come into serious question. Specifically, the deficiency is in the measured wave data base. Within this data base the percentage of occurrence of the short waves is extremely coarsely defined. The original SEP wave period distribution (built in for the SOWM wave model) had already expanded on the actual distribution of the percentage of occurrence of the waves by taking the lowest original two categories of ranges and splitting it into four categories.

In this context it is recognized that SEP had already been modified for this current CG project by incorporating both MII (USN 6.2 R&D program 1992) and MSI (USCG 1993 Boat Series Program) into SEP. This next, third modification to SEP for the Boat Series thus required a change in the distribution of wave periods to be defined without changing the number of these wave periods. This modification to SEP is analogous therefore to the change in the range of basic wave periods for which the transfer functions are calculated in SMP 93.

It is, of course valid to point out that the problem was attributable to the measured NOAA buoy wave data. Specifically, this measured wave data base contained only two wave period ranges that cover the entire range of the natural periods of the boat responses. They included in fact the majority of the entire range of dynamic boat responses and periods that correspond to long waves. It is therefore to be noted that the source wave data must have either of the following two wave period range data

(<3.5 sec, 3.6 - 7.5 sec)	Atlantic Ocean & Gulf of Mexico
(<6.0 sec, 6 - 7.5 sec)	Pacific Ocean

which is expanded into a set of four wave period data i.e.

3.2 sec, 4.8 sec, 6.3 sec , 7.5 sec

This expansion from two to four wave periods was made by distributing the probabilities of wave occurrence according to a straight line interpolation ie as a function of wave period distribution in the wave data base. For additional details see Appendix B.

The added wave periods to the SEP model for this CG study were as follows:

* * * *

2.5, 3.2, 3.6, 4.2, 4.8, 6.3, 7.5, ...

The * over the wave periods identify the original SOWM wave periods for the '93 USCG Boat series. The three longest periods in the wave data base were deleted to retain the required 15 period set. The original wave periods in the SOWM wave model input to SEP are:

3.2, 4.8, 6.3, 7.5, 8.6, 9.7, 10.9, 12.4, 13.8, 15, 16.4, 18, 20, 22.5, 25.7

The final 1993 USCG Boat Seakeeping Criteria wave periods are:

2.5, 3.2, 3.6, 4.2, 4.8, 6.3, 7.5, 8.6, 9.7, 10.9, 12.4, 13.8, 15, 16.4, 18

APPENDIX F

WPTO SENSITIVITY TO SEAKEEPING CRITERIA VARIATIONS

The object of this 1993 CG Boat Series study was to determine a basic set of seakeeping criteria by which the seakeeping merits of candidate boats for a particular mission can be judged. Attainment of the objective involved a detailed operability prediction process for which this base criteria set was established and then applied. It is to be recognized that the seakeeping criteria represent currently the weakest link in the logical chain in this operability prediction process as used as standard practice in the US Navy ship design cycle.

The merits of the seakeeping performance of a boat was measured by the expected percent time of operation that can be expected when deployed in various Coast Guard operational areas conducting a defined CG mission. The definition of the mission was provided within the Statement of Work and specified a series of critical locations on the boat as a function of boat speed. Further, the percentage of time that the mission will require the boat to operate at various speeds was similarly specified. This specified speed as well as the associated heading profile was then applied to the percent time of operation to yield the final seakeeping performance measure of the boat designated as the weighted percent time of operability, WPTO.

A limited study served as a final quality check on the accuracy of the base seakeeping criteria set in predicting the WPTO i.e. WPTO sensitivity to seakeeping criteria variations. This study, in turn, started by examining in some detail the motion criteria that most significantly affects boat performance and that can be changed as part of the design - roll motion. The limiting criteria that are identified in this roll criteria sensitivity examination were then similarly further examined.

The examination of the transfer functions of the boats led to the conclusion that roll motion is the single most important ship motion criteria affected by design by which the quality of the boats seakeeping can be judged. The pitch and heave responses of boats are essentially determined by their length and all boats will tend to operate at the lower speeds primarily in a wave contouring mode. It follows therefore that during a very large portion of the boats operations the pitch and heave responses will be the same for all three boats and that these responses can not be affected by detail hull shape design variations.

The accuracy of the roll motion criteria selected in this study or rather left unaltered from current US Navy ship design practice was established by examining the sensitivity of the figure of merit measure, WPTO, to really substantial changes in the value of the roll criteria. Specifically, it was decided to examine the base criteria sets significant roll value and a full + and - 50% variation of this value. In other words the base criteria set was employed and the computational runs were repeated for the following values of the roll criteria:

- 4 degrees of significant roll
- 8 degrees of significant roll - base value
- 12 degrees of significant roll

It is to be recognized that the logic implemented in the Seakeeping Evaluation Program, SEP, considers the operability of a ship or boat to be limited when any one of the seakeeping factors or criteria are violated or exceeded. In fact, it is the first criteria that limits ship or boat operability at any particular ship speed and heading in a specific seaway. This first criteria that limits is designated by SEP as the limiting seakeeping factor. Thus it is also to be recognized that different seakeeping

criteria can and do limit the operability of a vessel at various operating conditions or locations on the vessel.

When a given limiting seakeeping factor or criteria is lowered there are two outcomes. These outcomes are changes in the overall WPTO and changes in the identity of the new limiting criteria. In case of the operability measure WPTO, the change may range from negligible small to a significant change. If this change is small it follows that the accuracy of the varied criteria is adequate since its value does not particularly affect the overall payoff function, the WPTO. Conversely, if the WPTO change is large for a change in the value of the limiting criteria then the accuracy of the limiting criteria is very important.

In case of the limiting criteria or seakeeping factor outcome it may be that either the same criteria still limits the operations or that another criteria then curtails operability. At any given speed there are 24* separate limiting seakeeping criteria results identified by SEP for the various headings. Therefore at any speed either one or more criteria will be identified as the limiting seakeeping factor. For a given speed, the relative frequency of occurrence of a particular seakeeping factor at various headings can thus be expressed either as a number up to 24 or as a percentage with a value up to 100%. The relative frequency of occurrence of all of the limiting seakeeping factors at a particular speed can thus be represented as the percentage that they individually limit the operation. The specific importance of the limiting seakeeping factors or criteria were extracted as their limiting percentage from the SEP output files.

It is to be recorded that this limiting criteria frequency of occurrence data is computed for the 95 percent confidence band of the waves whereas the measure of merit the WPTO includes all of the waves.

Typical WPTO results of the roll motion set of sensitivity calculations were obtained for the 82-Ft cutter operating at low speed in the Atlantic and Gulf of Mexico using the annual wave data. These data are presented in part a of Figure F-1. The graph of WPTO consist for each location identified by the gridpoint as three vertical bars. These correspond respectively to the WPTO for the roll criteria at 4, 8 and 12 degrees.

It is clear from these results that the WPTO's reach essentially a nearly stable value at each of the geographic locations once the 8 degree significant roll value is attained. It is thus concluded that the 8 degree significant roll criteria represents a satisfactory roll criteria value. Relaxing this criteria to accept the much larger 12 degree significant roll limit simply does not result in any appreciable gain in the boats operability.

Once the operational area shifts to the Pacific and the speed increases to the high speed as illustrated in part b of Figure F-1 the differences in operability resulting from the use of 4, 8 and 12 degree criteria levels shrink very substantially. However, the basic trend of the operations in the Atlantic, which indicates that the 8 degree roll limit is the lowest acceptable roll criteria, are still supported in the Fall Pacific data. It is apparent that in the geographic location with the mildest sea conditions in the CG wave data base, P-625 off shore of southern California, roll motion is of lesser importance and the differences in the WPTO as a function of the roll criteria levels virtually disappear.

WPTO and Relative Importance of Limiting Criteria

Figures F-2 and F-3 were prepared to expand on the WPTO result variations with the roll criteria levels shown in Figure F-1.

This data expansion presents both the limiting criteria frequency of occurrence data as well as the associated WPTO in three columns of graph frames corresponding again from left to right in the figures to roll criteria limits of 4, 8, and 12 degrees.

4 Degree Roll Limit

It is immediately apparent when the data at the 4 degree criteria are examined that fully 100% of the criteria which limit the boats operability in the Atlantic area A-405 (Figure F-2) are the result of excessive roll. Thus when the acceptable roll value is relatively small, it will then tend to become the criteria which most seriously limits the boats operability.

When the same 4 degree criteria level is applied in the typical Pacific operational area P-610, the relative importance of the roll motion is clearly reduced from the 100 % in the Atlantic to a much lower less than 35% level. In fact, it is to be noted that in this typical Pacific operational area the roll criteria (33%) is no longer even the most important limiting criteria because this is now represented by the more than 50% occurrence of the tipping MII. Slamming (12%) also occurs as one of the limiting criteria of boat operation in the Pacific when the very restrictive 4 degree roll criteria is employed.

8 Degree Roll Limit

When the 8 degree criteria level is examined in the Atlantic the same trend of limiting criteria levels is noticeable as was the case for the Pacific i.e. the most important or frequent limiting criteria is tipping (50%), followed next by roll (38%) and finally slamming (12%). Thus the criteria which limit boat operations at the 4 degree roll criteria limit in the Pacific are the same ones which limit the boats operations in the Atlantic when the 8 degree roll criteria is employed. In the Pacific when the base 8 degree roll criteria is applied, the tipping criteria represents about 70% of the limiting criteria whereas slamming and pitch angle represent the much less important or frequently incurred limiting criteria.

12 Degree Roll Limit

By the time the 12 degree roll criteria level is applied in either the Atlantic location or the Pacific location the tipping MII is clearly most important and the identity and order or relative importance of the limiting criteria is the same for both oceans i.e. tipping, slamming and MSI.

The sensitivity of WPTO to variations in the limiting criteria identified by the roll criteria variations were examined in some detail following these initial sample results for roll. Specifically, the variations in the MII tipping criteria, slamming and finally MSI were examined for the base criteria set that includes the base roll criteria of 8 degrees. Figures F-4, F-5 and F-6 were prepared for the MII, slamming and MSI criteria variation as a function of geographic location at all three ship speeds in a format similar

to Figure F-1.

WPTO for MII Criteria Variations

The MII criteria variation (Figure F-4) was expanded beyond the initial +/- 50% of base value to attempt to push this criteria to a logical extreme in order to investigate if the acceptance of very high rates of this most limiting criteria would expand the WPTO by a significant amount. The MII's bar graphs thus consist from left to right to values of 1.05 MII's per minute (most restrictive) to 2.1 MII's per minute as the base MII criteria value, 3.15 tips per minute and finally the least restrictive of 6 tips per minute. The results indicate that the base MII value is an acceptable value because there is little operability to be gained once this value is selected. Relaxing the MII criteria to permit as many as 6 tips per minute which corresponds to an expected time between tipping MII's of only 10 seconds simply does not add at the low speed though some gains are registered at the higher speeds.

WPTO for Slamming Criteria Variations

The slamming criteria variation (F-5) indicated that even the most restrictive criteria value of allowing only 15 slams per hour or alternatively 1 slam every four minutes do not alter the WPTO. It is thus concluded that the particular value of the slamming criteria for boats is not a particularly useful discriminator of boat operability.

WPTO for MSI Criteria Variations

The MSI criteria variation (F-6) were made for a much wider range of the base criteria than was the case for any of the other criteria. The Statement of Work had suggested two different levels of MSI as well as a fatigue decreased proficiency rating that subsequent analysis indicated the boats would not experience. This fatigue rating was used to specify the most restrictive value of acceptable MSI. The suggested MSI criteria specified in the Statement of Work also corresponded to different exposure times ranging from 8 hours for the most restrictive MSI criteria value to a 30 minute value. The MSI criteria were all translated for a common time period of 4 hours:

MSI Criteria Level	MSI Relative Severity Rating	MSI % Expected in		Corresponding RMS Vertical Acc for Toe = 5 Sec
		30 min	4 hours	
1	Most Stringent	1.1	7.9	.0393 g
2	Base Criteria	5.0	19.6	.0650 g
3	Less Stringent	14.1	35.0	.1020 g
4	Least	50.1	50.1	.1500 g

As was done for the MII criteria variation, the MSI's bar graphs of Figure F-6 thus consist from left to right of MSI criteria level values of 7.9% in four hours (most restrictive) to 19.6 % MSI's in 4 hours as the base MSI criteria value, 35.0 % MSI's in 4 hours and finally the least restrictive of 50 % in 4 hours. The WPTO results indicate that at the lower speed there are substantial gains to be made when the MSI level is relaxed from the most

restrictive to the least restrictive level. However, it is also clear that the gains in operability to be made by relaxing the criteria beyond the base criteria value are small. This same trend is reinforced by the results at the higher speeds. It is therefore concluded that the base MSI criteria value is a rational one to employ. This is particularly considered to be valid because this MSI criteria value corresponds to a level found to be just acceptable during 1992 Experiments with US Navy enlisted Human Subject Volunteers. These subjects are representative of the crews of US Navy and US Coast Guard vessels conducting minor physical tasks for one hour durations.

Limiting Criteria for MII Variation in F-7, F-8

There is essentially no effect on WPTO at lower speed when the acceptable MII's are relaxed beyond the base line value, the only difference observed is that the actual limiting criteria change in importance. As the MII criteria value is relaxed from the most severe one the importance of the tipping decreases as roll begins to increase and then slamming increases in importance. The same general conclusion is valid for operations at the economical speed, although here the roll does become a limiting criteria, being instead by the lateral force estimator which is the acceleration in the plane of the deck largely induced by roll angle. Slamming remains the third most important limiting criteria.

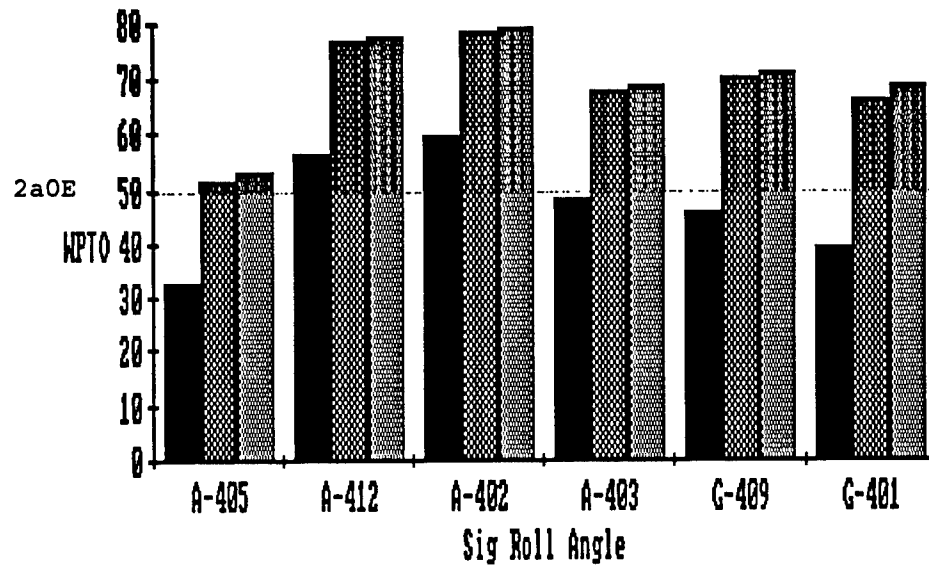
Limiting Criteria for MSI Variation in F-9, F-10

The importance of MSI as a limiting criteria is demonstrated particularly well in Figure F-9 for the low speed operations. Here at the most stringent MSI criteria level fully ~55% of the reasons for the restriction in boat operations is the result of the MSI. With roll angle, tipping and slamming in that order representing the less important criteria. Once the base MSI criteria value is employed the WPTO gains and now MSI is no longer a limiting criteria, instead it is tipping, roll and slamming in that order which limit operations. Further relaxations of the MSI criteria neither gain a substantial amount of additional operability nor do the order of the limiting criteria vary i.e. they remain in the same order as they were when the most restrictive MSI level was applied except of course MSI as a leading cause for the operability curtailment is now gone. At the higher speed, the differences in WPTO and in the limiting criteria further decrease. It is therefore concluded that the base criteria MSI limit is the appropriate limit.

Limiting Criteria for Slamming Variation in F-11, F-12

The secondary importance of the precise value of the slamming criteria is demonstrated for the low speed and the economical speeds in Figures F-11 and F-12. Variations in the slamming criteria value do not particularly affect the WPTO, nor do they strongly affect even the identity or order of the limiting criteria at a particular speed. At the low speed tipping, roll angle and slam limit operations whereas at the economical speed of 8 knots tipping represents over 90 percent of the reason for operation curtailment with slamming making up the balance independent of the value of the selected slamming criteria. The selection of the slamming criteria value for the evaluation of the CG boats is thus not critical, the base criteria value is therefore by default adequate.

- a) Low Speed for 82-Ft Cutter in the Atlantic and Gulf of Mexico Operational Areas, Annual Wave Data (File CG100.grf)



- b) High Speed for 82-Ft Cutter in the Pacific Operational Areas, Fall Season Wave Data (File CG101.grf)

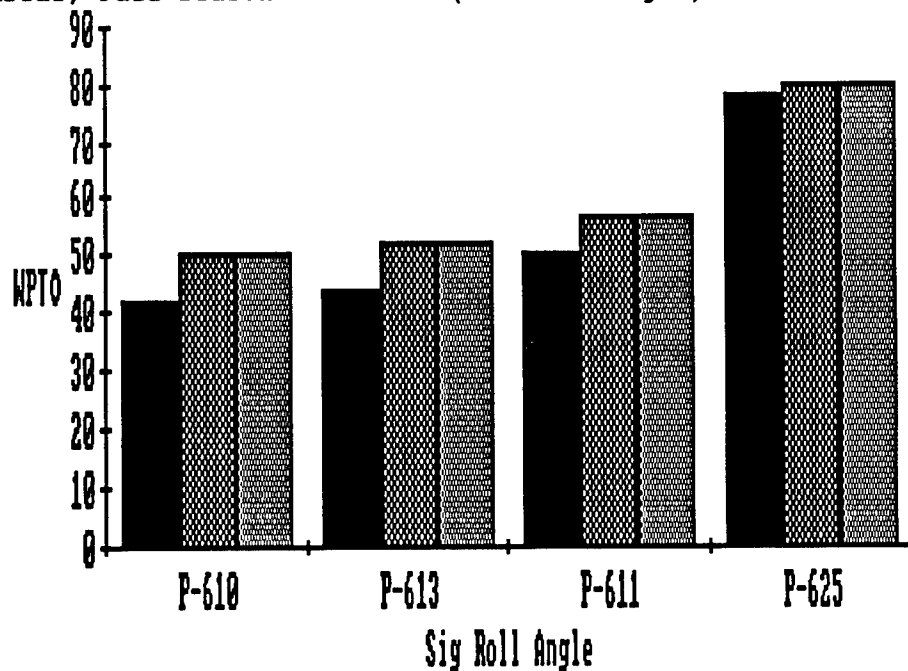


Figure F-1 Roll Criteria Variation (4, 8, 12 Deg) Effect on PTO Base Criteria Set, except for Roll

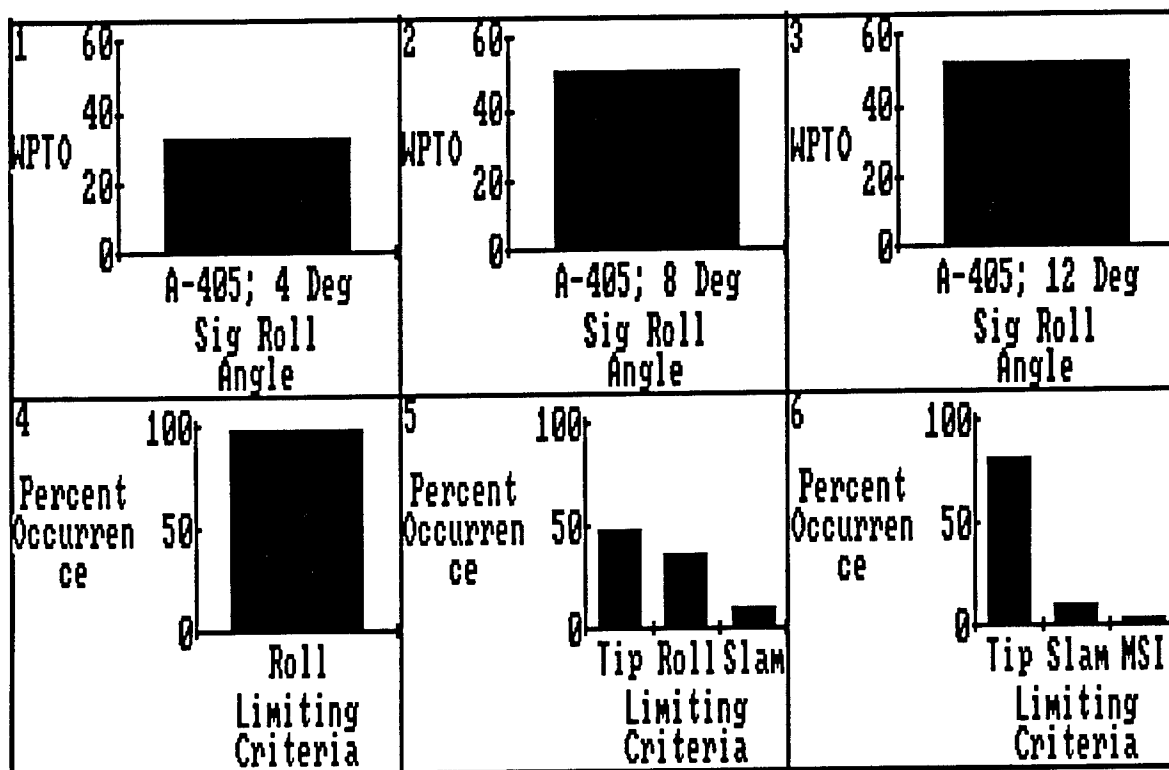


Figure F-2 Example of the Effect of Roll Criteria Variations of 4,8 and 12 Degrees on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Low Speed of 5 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1001.GRF

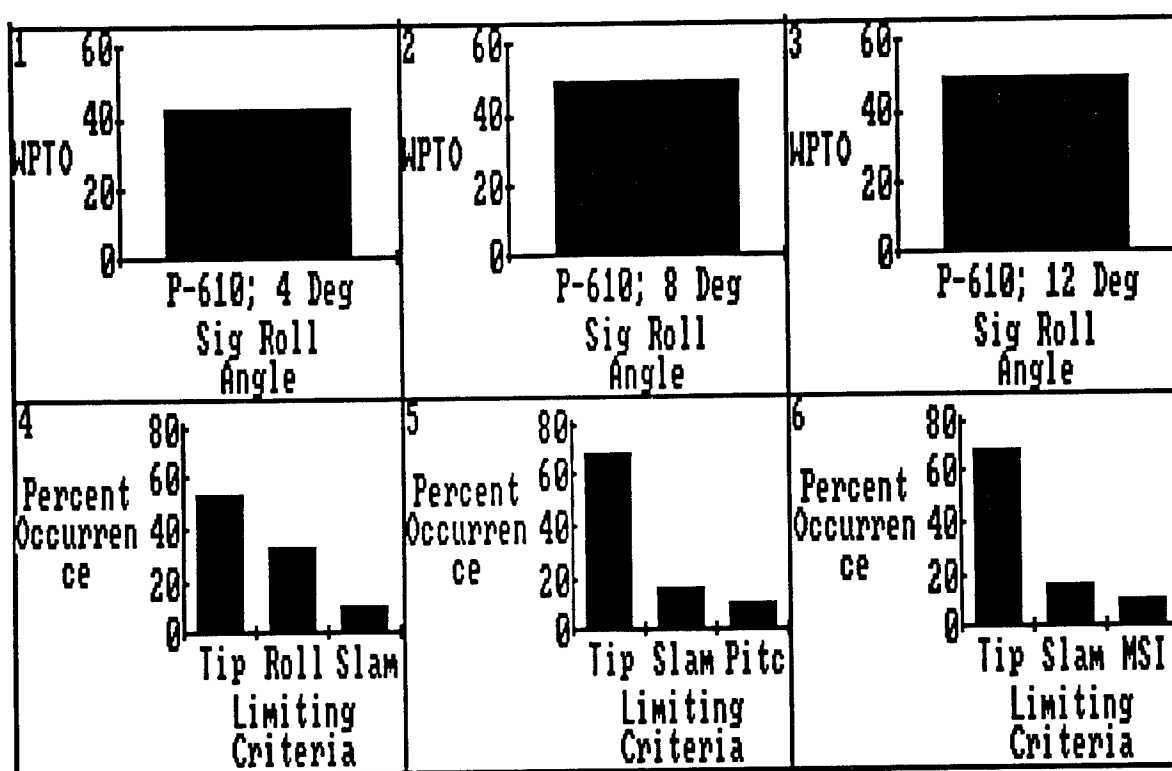
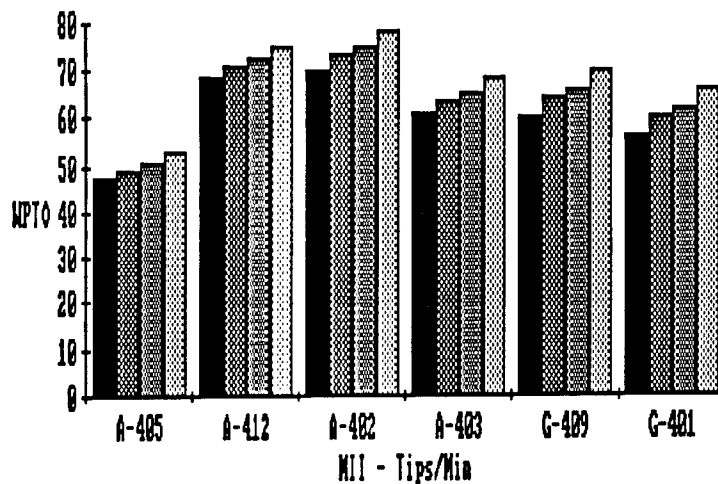
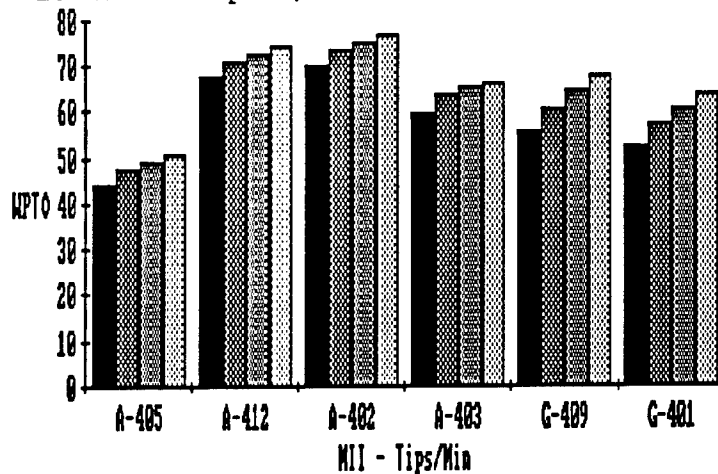


Figure F-3 Example of the Roll Criteria Variations of 4,8 and 12 Degrees on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at High Speed of 18 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1002.GRF

c) High Speed; File CG104.GRF



b) Economical Speed; File CG103.GRF



a) Low Speed; File CG102.GRF

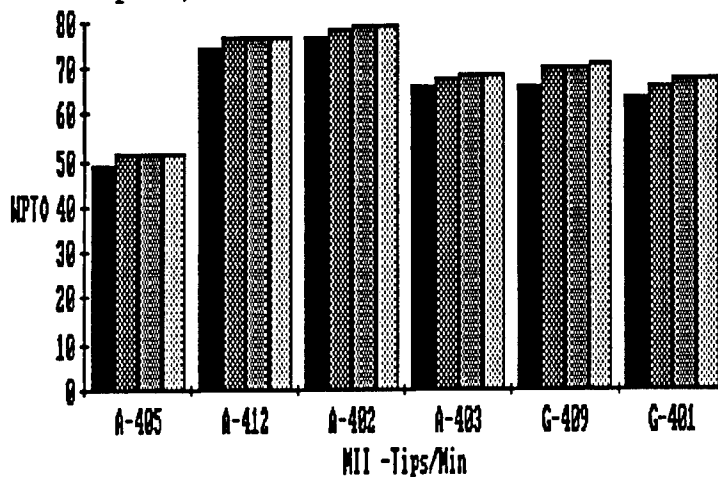
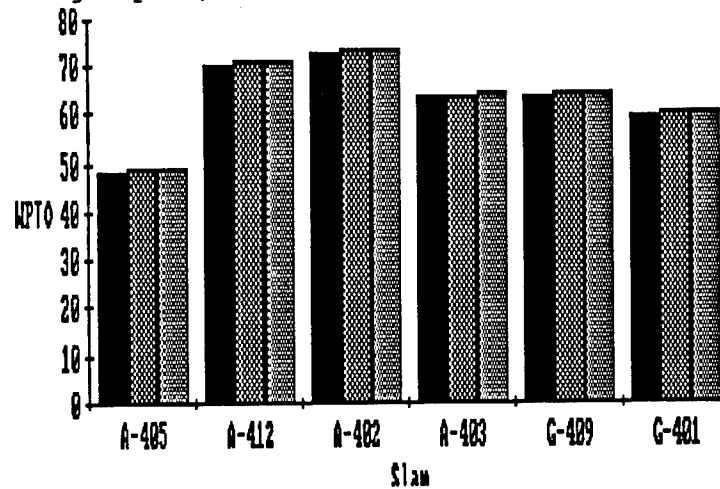
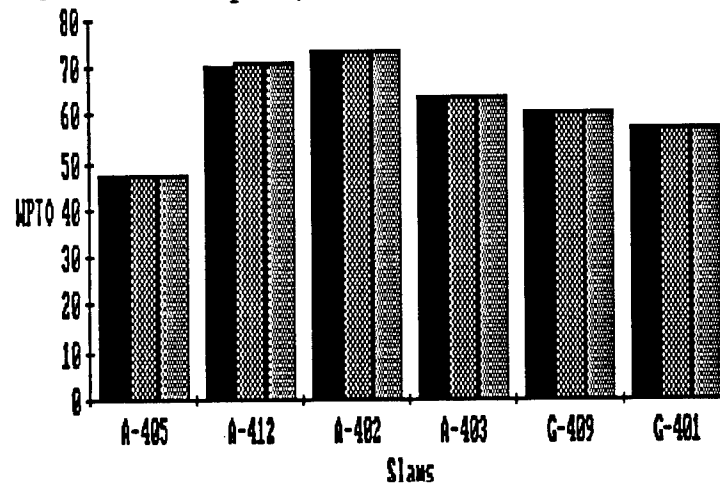


Figure F-4 MII Criteria Variation (1.05, 2.1, 3.15 and 6.0 Tips/Min) Effect on PTO; Base Criteria Set, except for MII 82-Ft Cutter in Atlantic and Gulf of Mexico Operational Areas, Annual Wave Data

c) High Speed; File CG107.GRF



b) Economical Speed; File CG106.GRF



a) Low Speed; File CG105.GRF

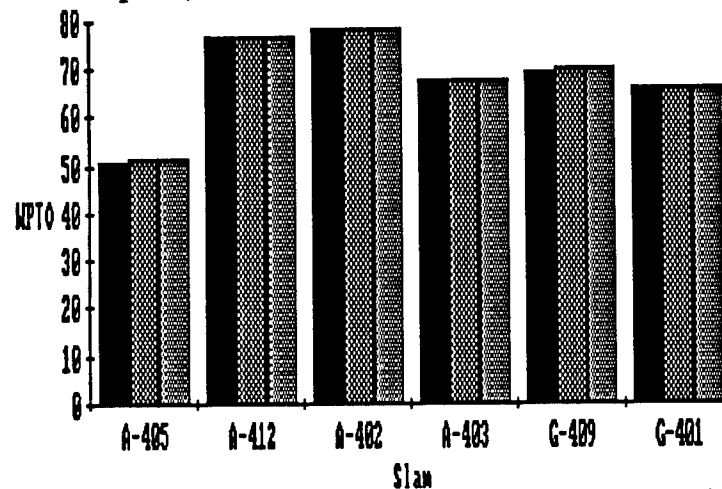
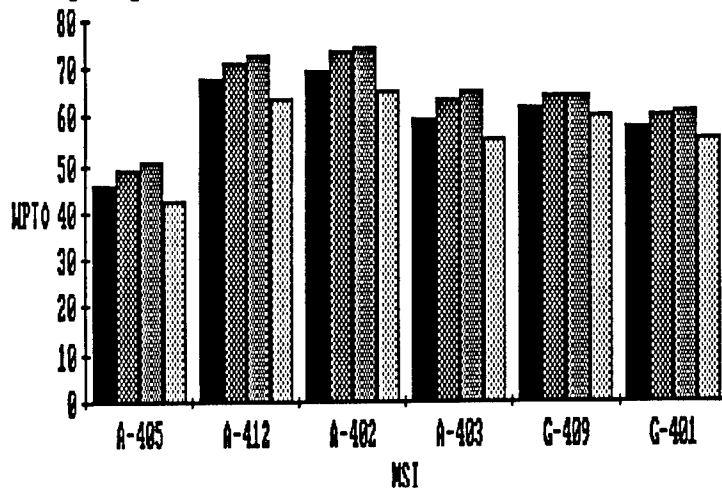
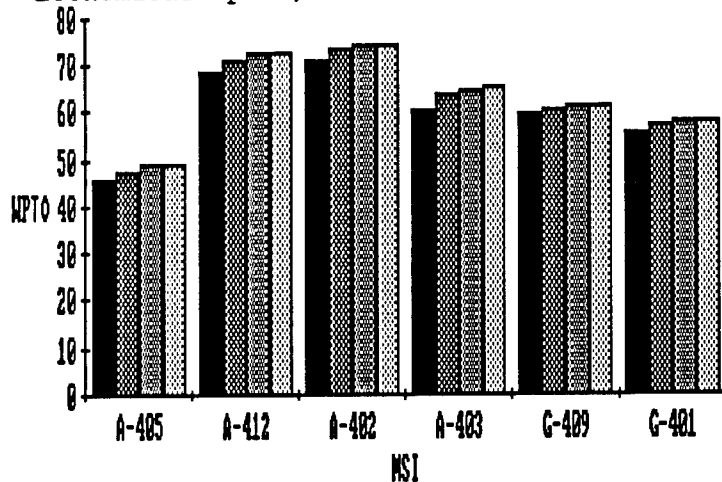


Figure F-5 Slamming Criteria Variation (15,30 and 45 Slams/Hr) Effect on PTO; Base Criteria Set, except for Slamming 82-Ft Cutter in the Atlantic and Gulf of Mexico Operational Areas, Annual Wave Data

c) High Speed; File CG110.GRF



b) Economical Speed; File CG109.GRF



a) Low Speed; File CG108.GRF

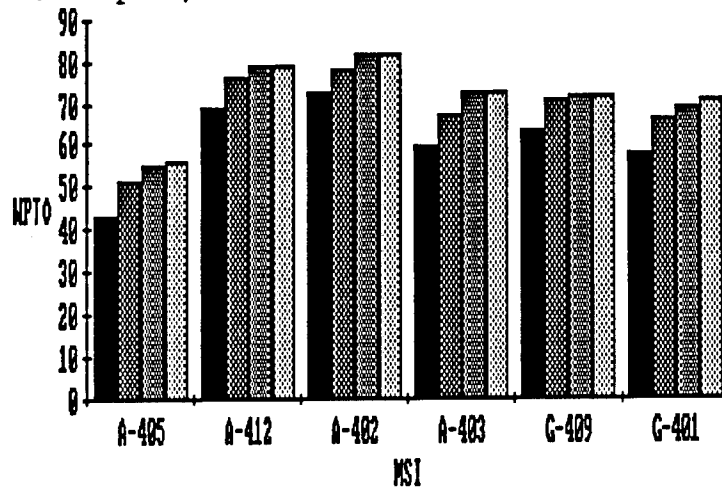


Figure F-6 MSI Criteria Variation (7.9, 19.6, 35 and 50%/4Hr Exposure) Effect on PTO, Base Criteria Set, except for MSI 82-Ft Cutter in the Atlantic and Gulf of Mexico Operational Areas, Annual Wave Data

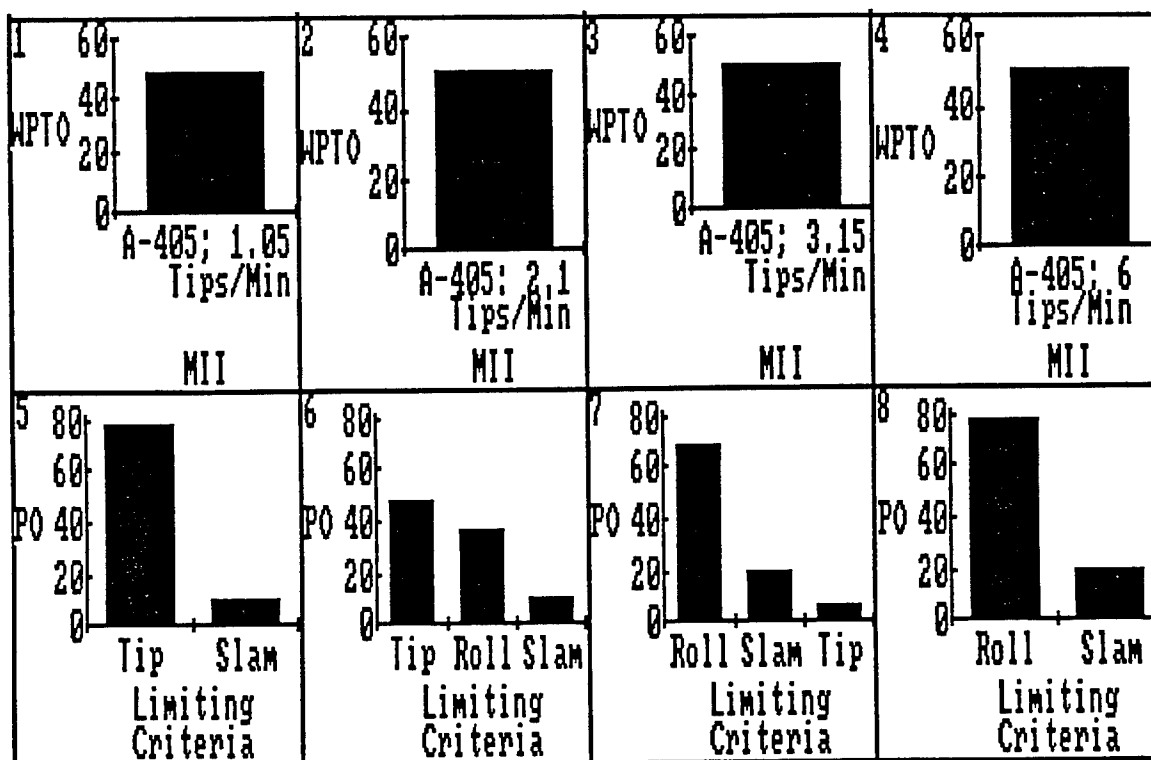


Figure F-7 Example of the Effect of MII Criteria Variations of 1.05, 2.1, 3.15 and 6 Tips/Min on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Low Speed of 5 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1003.GRF

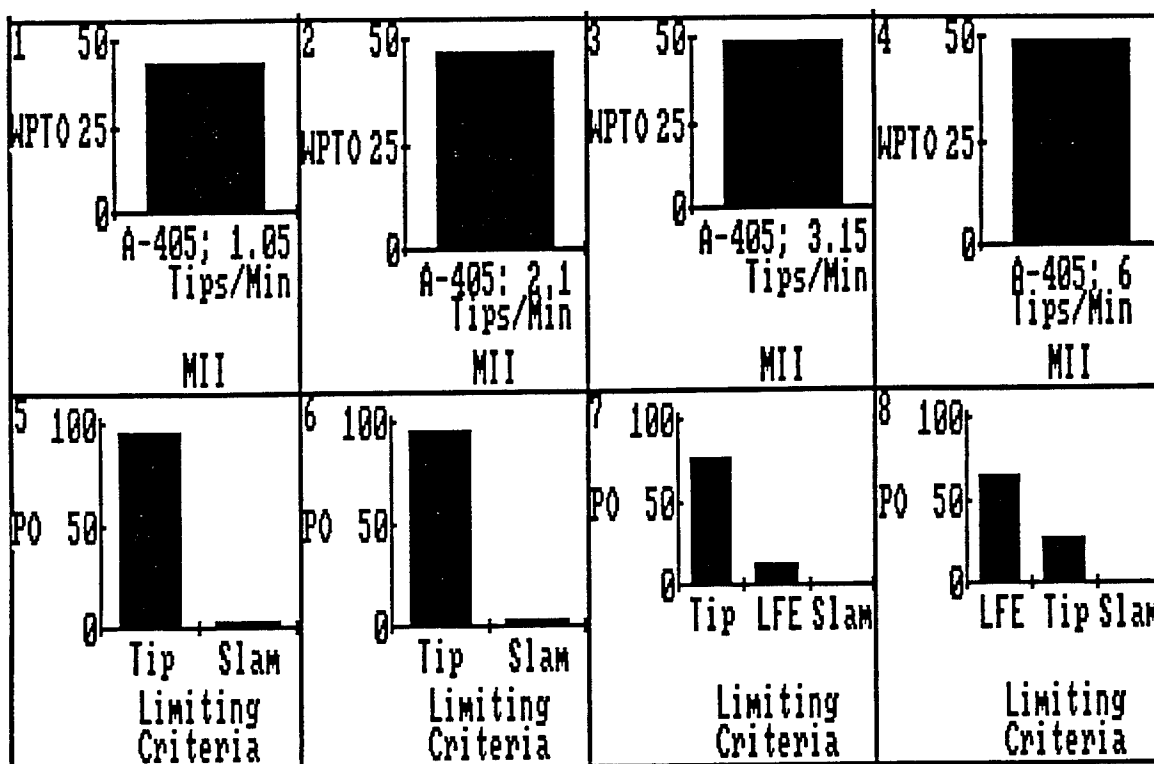


Figure F-8 Example of the Effect of MII Criteria Variations of 1.05, 2.1, 3.15 and 6 Tips/Min on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Economical Speed of 8 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1004.GRF

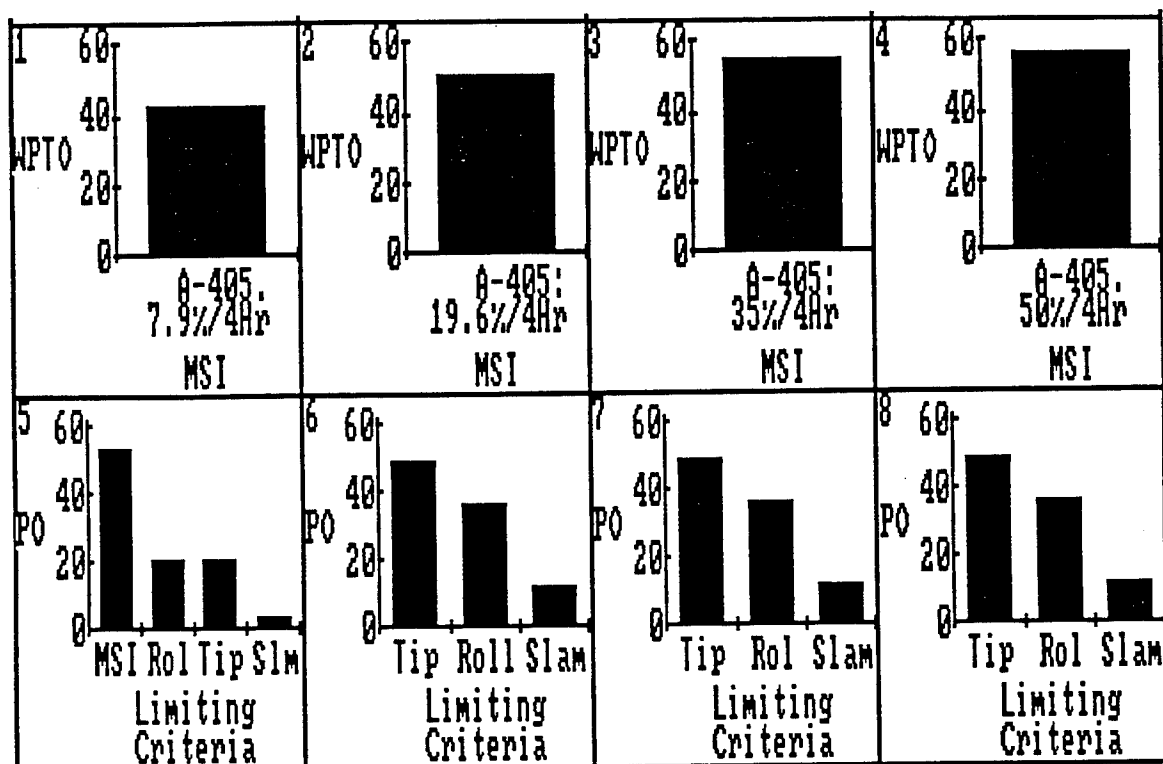


Figure F-9 Example of the Effect of MSI Criteria Variations of 7.9, 19.6, 35 and 50%/4Hr Exposure on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Low Speed of 5 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1005.GRF

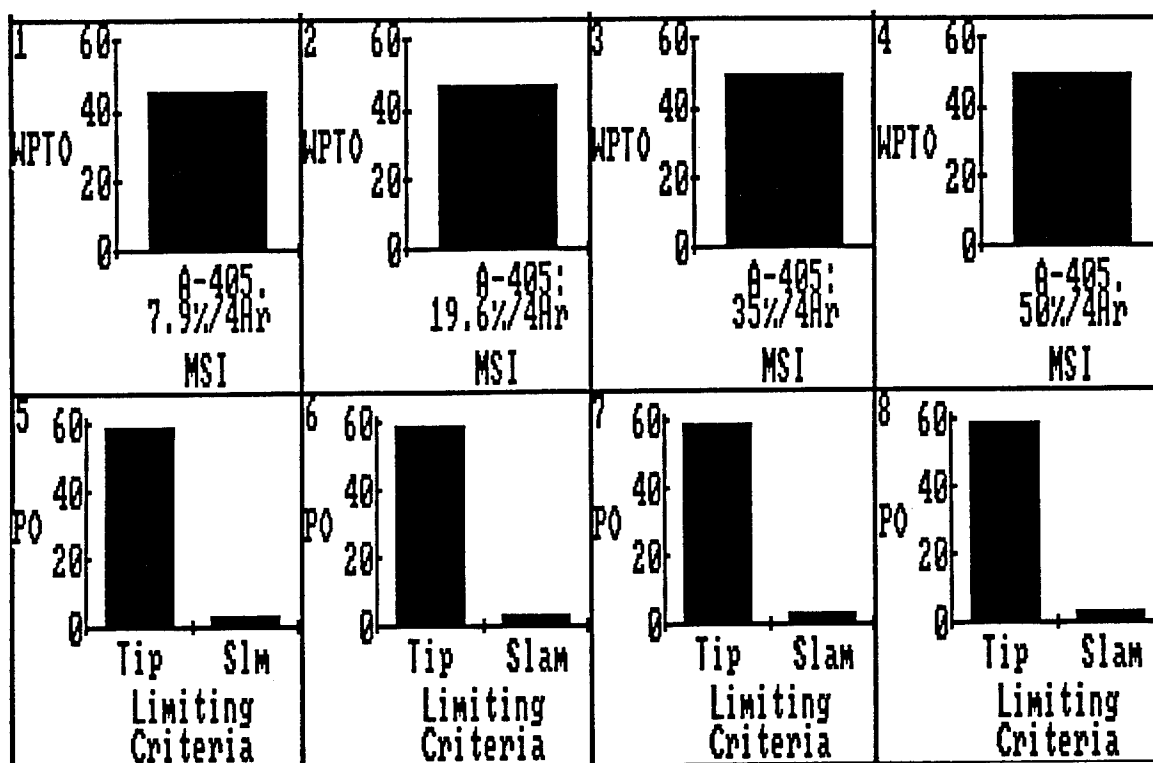


Figure F-10 Example of the Effect of MSI Criteria Variations of 7.9, 19.6, 35 and 50%/4Hr Exposure on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Economical Speed of 8 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1006.GRF

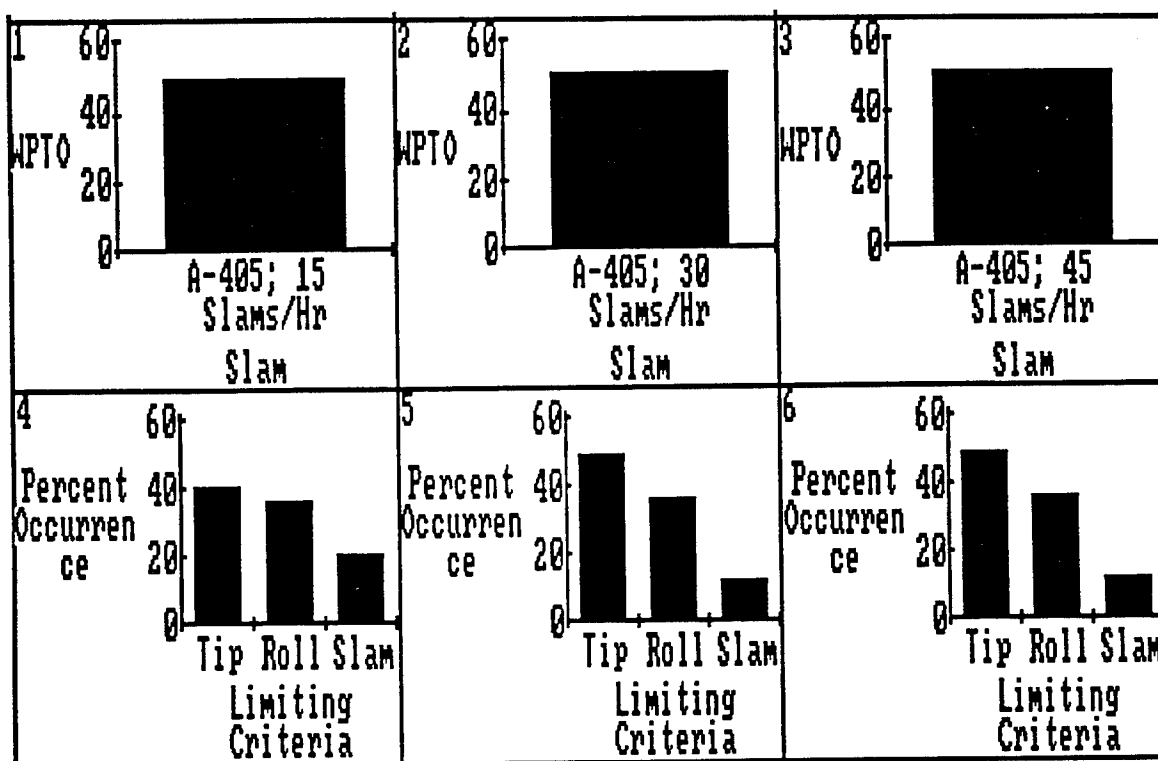


Figure F-11 Example of the Effect of Slam Criteria Variations of 15, 30 and 45 Slams/Hr on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Low Speed of 5 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File Cg1007.GRF

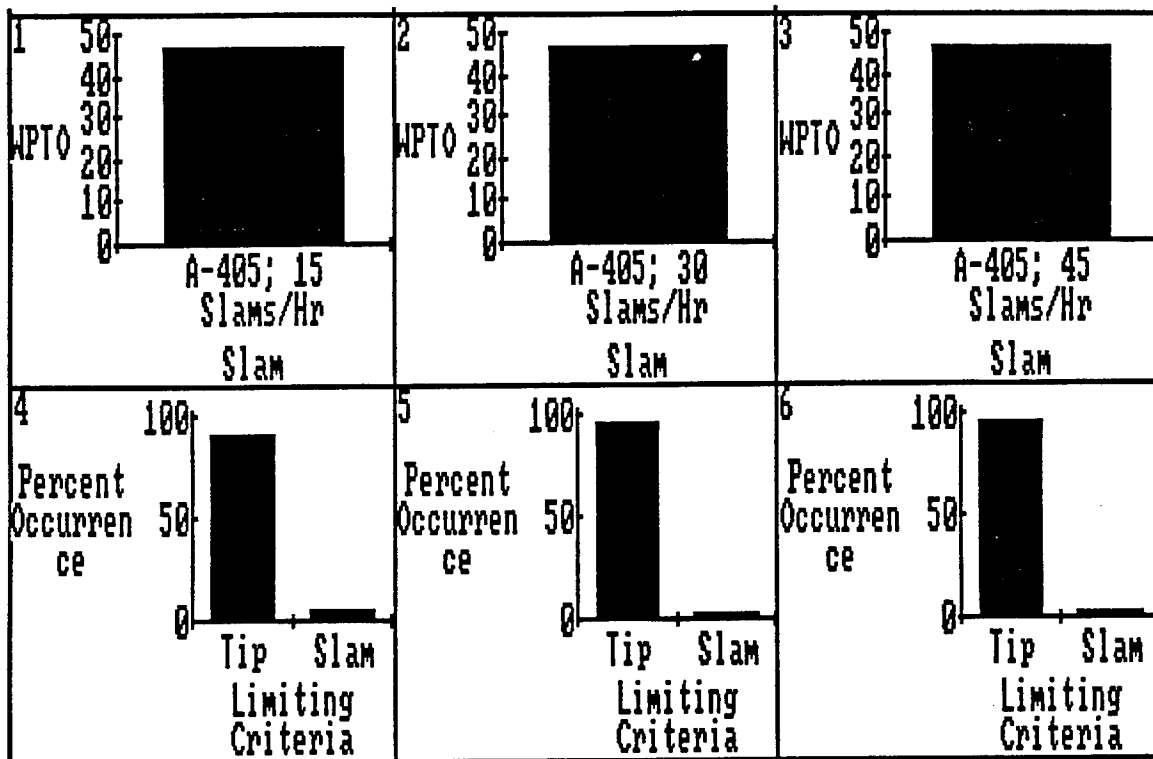


Figure F-12 Example of the Effect of Slam Criteria Variations of 15, 30 and 45 Slams/Hr on the Identity and Percentage of Occurrence of the Limiting Criteria as well as the Weighted Percent Time of Operation, WPTO. 82-Ft Cutter Operating at Economical Speed of 8 knots in the most northern Atlantic Area A-405 for Annual Wave Data; File CG1008.GRF

APPENDIX G

USCG STATEMENT OF WORK FOR 82' WPB

STATEMENT OF WORK
82' WPB CAPABILITY REPLACEMENT
SEAKEEPING BASE LINES AND
SOURCE SELECTION CRITERIA RECOMMENDATIONS

1. Scope

1.1 Introduction

An effort shall be performed as part of the 82 Foot Patrol Boat Capability Replacement Project to delineate and make recommendations for seakeeping performance values to be used in the Circular of Requirements and the Source Selection process. In addition, seakeeping performance base lines of current vessels shall be established and consultations to the Project Manager on Source Selection shall be provided.

1.2 Background

As part of the 82 Foot Patrol Boat Capability Replacement Project, there is a need to establish criteria for evaluating possible replacements. Specifically, there is a need to define evaluation criteria and possible constraints in the areas of human factors engineering and seakeeping parameters which can be used to maximize crew endurance and safety while still meeting other mission requirements. These areas must be more fully understood to be effectively applied in the acquisition process.

Ship motions have a significant effect on a crew's ability to do their work. Vertical accelerations (heave) induce motion sickness in the short term and chronic fatigue (Sopite syndrome) in the long term. Pitching motions amplify vertical accelerations. A vessel's rolling motion is uncomfortable and creates safety problems in the extreme.

What has been missing is the ability to quantify these effects in sufficient detail so that they can be addressed in the selection process for new procurements. Scientific work accomplished over the last two decades may now allow us to quantify the effects for source selection decisions. The effort specified below will gather that data into a usable format and allow the Coast Guard to make intelligent cost-benefit trade-offs in specifying the level of allowable risk.

2. Applicable Documents

Climatic Studies for NDBC Buoys and Stations Update 1; National Data Buoy Data Center; National Weather Service; February 1990

Comparative Characteristics of United States Coast Guard 95' and 82' Class Patrol Boats (WPB); Thomas J. Coe and Ryan R. Young; U.S. Coast Guard Research and Development Center; April 1985.

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STATEMENT OF WORK FOR SEAKEEPING BASE LINES AND
SOURCE SELECTION CRITERIA RECOMMENDATIONS

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Improvements to Capability and Prediction Accuracy of the Standard Ship Motion Program SMP81; W. G. Meyers and A. E. Baitis; David Taylor Naval Ship Research and Development Center; DTNSRDC/SPD-0936-04; September 1985.

A Method to Define Ship Motion Criteria; W. L. Thomas, et. al.; Carderock Division, Naval Surface Warfare Center; CARDEROCKDIV/SHD-1309-01; November 1992.

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Seakeeping Evaluation Program (SEP) - Revision 1: Users Manual; K. K. McCreight and R. G. Stahl; David Taylor National Ship Research and Development Center; DTNSRDC/SPD-1223-02; August 1987.

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3. Requirements

3.1 Seakeeping Performance Indices

3.1.1 Base Line Seakeeping Performance Indices

Using the methods originally in *Principles of Naval Architecture* (1989) and updated into the U.S. Navy's standard Seakeeping Evaluation Program (SEP-1987), calculate and report a total of 80 SPI-1 Mission Effectiveness Indices. The 80 Indices are for 4 different vessels operating under 2 possible operational scenarios in 10 possible geographic areas. Each mission Effectiveness Index calculation shall consider 10 limiting constraints. Details of the vessels, operating scenarios, geographic areas, and limiting constraints are contained in Section 6.1. Vessel motions shall be calculated using the Standard Ship Motion Program (SMP) and validated with published vessel trial data. Use of appropriate prediction algorithms and transfer functions shall be used for speed and sea state combinations out of the SMP range of accuracy.

3.1.2 Seakeeping Performance Index Sensitivity Analysis

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Conduct and report the results of a sensitivity analysis on limiting constraint magnitudes on Mission Effectiveness Index values for each of the 80 Vessel Type/Operating Scenario/Operating Area combinations. The results of each sensitivity analysis shall be the importance of the individual constraints as measured by the impact of constraint variability on the Mission Effectiveness Index. Rank order of the limiting constraints is to be among the techniques used to determine the most important mission degrading constraints.

3.1.3 Seakeeping Performance Index and Limiting Constraint Recommendation

Using the results of Tasks 3.1.1 and 3.1.2, develop, justify, and report recommendations for limiting constraints and Seakeeping Performance Indices to be specified in a Circular of Requirements or used as Source Selection criteria for procuring a Coast Guard patrol boat approximately 25 meters in length with a semi-displacement hull form and an operating area near the continental United States.

3.2 Selection Criteria Consultation

The Principle Investigator shall provide up to 0.25 staff years (0.10 in Fiscal Year 93, 0.15 in Fiscal Year 94) of effort to Project Manager, 82' Patrol Boat Capability Replacement, Commandant (G-AWP), U.S. Coast Guard Headquarters, as a consultant on seakeeping performance for development of the Circular of Requirements and Source Selection Criteria for the 82' Patrol Boat Capability Replacement Project and as a consulting member of the Technical Evaluation Team during Proposal Reviews. Effort under this section shall be in addition to and exclusive of any effort expended in completing requirements of sections 3.1, 4.1, 4.2, 5.1 and 5.2.

4. Quality Assurance

4.1 Status Briefing

The Principle Investigator shall deliver a status brief every 2 weeks on all contract effort to Commandant (G-AWP), U.S. Coast Guard or a designated representative. The briefing shall be verbal and delivered in person or by telephone.

4.2 Level of Review

All written deliverables specified below shall be reviewed and approved by the Principle Investigator's immediate supervisor or higher authority before submittal and delivery.

5. Deliverables

5.1 Monthly Summary Reports

The Principle Investigator, through a supervisor, shall submit monthly, summary, letter reports to Commandant (G-AWP), U.S. Coast Guard throughout the life of the contract. These reports shall contain:

- a. Results and supporting calculations of all Seakeeping Performance Index and Sensitivity Analysis calculations completed since the last monthly

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report. All calculations specified in sections 3.1.1 and 3.1.2 are to be completed and reported no later than 1 April 1993.

b. Summary of consulting effort as specified in section 3.2 since last monthly report including staff days expended and available staff days remaining.

c. Summary of other contract effort since last monthly report including as estimate and discussion of current technical and schedule risk in completing the contract as specified.

5.2 Seakeeping Performance Index and Limiting Constraint Recommendation Report

The Principle Investigator, through a supervisor, shall submit a letter report to Commandant (G-AWP), U.S. Coast Guard detailing the effort and resulting facts, conclusions, and recommendations specified in section 3.1.3. This letter report shall be submitted no later than 1 May 1993. The Principal Investigator shall deliver a formal briefing on the report contents at Coast Guard Headquarters on or about 15 May 1993.

5.3 Consultation Services

The Principle Investigator shall provide consultation services in response to written and verbal requests from Commandant (G-AWP), U.S. Coast Guard as specified in section 3.2. Reporting of consultations shall be summarized in monthly reports specified in section 5.1. Local travel to be funded by the Principle Investigator's parent command. Travel outside the greater Washington, DC area shall be funded by Commandant (G-AWP) under a separate account.

6. Notes

6.1 Seakeeping Performance Index Parameters

6.1.1 Vessels Considered

4 vessels shall be considered. The 4 vessels are a 47' Motor Life Boat, an 82' Patrol Boat, an 110' Patrol Boat with active roll-damping, and an 110' Patrol Boat without active roll-damping.

6.1.2 Operational Scenarios Considered

Each vessel shall have 2 operational scenarios considered. The first scenario shall be for transiting point to point with the vessel operating 85% of the time at best economical speed and 15% of the time at maximum sustained speed. The second scenario shall be for special evolutions with the vessel operating 100% of the time at bare-steerage-way.

The probability of a vessel operating on any particular heading of a 16 point compass shall be 6.25%.

6.1.3 Sea States Considered

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The sea state profiles shall be chosen from operating areas and attendant wave height and wave period profiles outlined in "Climactic Studies for NDBC Buoys and Stations Update 1" (February 1990). The probability of a vessel operating in any particular month shall be 8.33%. 10 data sites shall be chosen in order to give a representative sample of Coast Guard Operating areas and sea state conditions.

6.1.4 Vessel Characteristics Considered

Sources for vessel Response Amplitude Operator (RAO) curves are:

Comparative Characteristics of United States Coast Guard 95' and 82' Class Patrol Boats (WPB); Coe and Young; 1985.

Engineering and Operational Characteristics of a 110 Foot Island Class Patrol Boat (WPB); Young; 1987.

Technical Characteristics Verification of the Prototype 47 FT MLB; Milburn; 1991.

6.1.5 Limiting Constraints Considered

The limiting constraints (measured at the bridge helm station) for the seakeeping performance indices are:

Rms Roll Angle, degrees	4.0
Rms Pitch Angle, degrees	1.5
Rms Vertical Acceleration, g	0.2
Rms Lateral Acceleration, g	0.1
Motion Sickness Incidence (MSI)	50% in 4 hours
Slamming and Deck Wetness Frequency	20/hour
Propeller Emergence Frequency	25/hour
Motion Sickness Vibration Limit per ISO 2631/3 and ASTM F1166-32.10.1.4	30 minutes
Whole Body Vibration Safety Limit per ISO 2631/1 and ASTM F1166-32-10.1.1	8 hours
Motion Induced Interruptions (MII)	2.1/minute

The above limiting parameters are starting points. The Principle Investigator may recommend deletions, changes or additions (i.e. Draft ISO 2631/4 standards) as work progresses.